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Development of Methods to Improve Performance of Surface Mine Sediment Basins

Skelly and Loy
Harrisburg, PA

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The control of erosion and sedimentation from disturbed lands is a subject of increasing interest, particularly in the area of surface mining. Because of the hydrologic conditions and steep terrain in Appalachia, a large share of the eroded material comes from surface mines, largely controlled through the use of sedimentation ponds. With the passage of the 1977 Clean Water Act which has a specific effluent limitation of total suspended solids from surface mine sedimentation basins, the Environmental Protection Agency has mandated that sediment basins be designed to achieve a specific effluent quality. Two methods for achieving this goal have been investigated during this study: physical modifications to sediment basin design parameters and the use of chemical coagulants. As a result of this study, methods have been determined for upgrading sediment pond efficiencies by physical modifications and coagulant usage.

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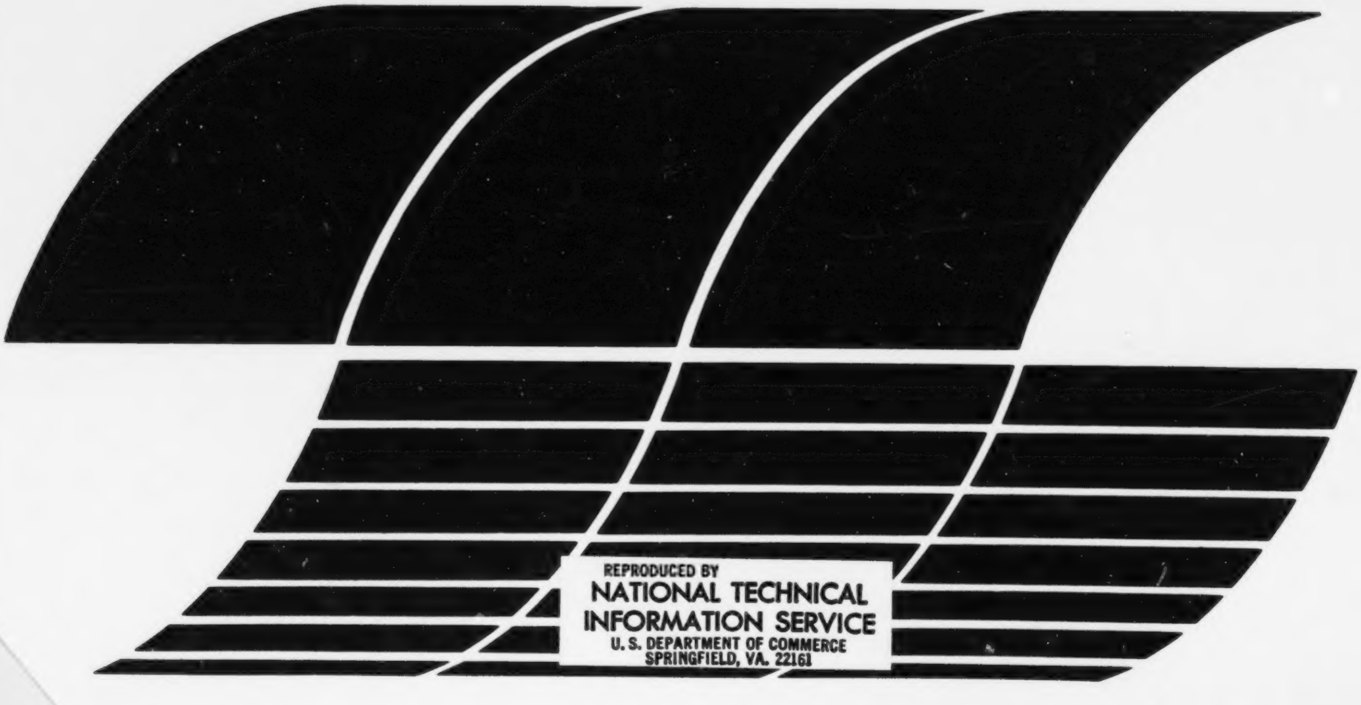

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EPA-600/7-80-072
April 1980

DEVELOPMENT OF METHODS TO IMPROVE PERFORMANCE OF SURFACE MINE SEDIMENT BASINS

Phase I

by

Charles E. Ettinger
Skelly and Loy
Harrisburg, Pennsylvania 17110

Contract No. 68-03-2677

Project Officer

Roger C. Wilmoth
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study outlines methods to improve the performance of surface mine sedimentation basins in order to meet the current effluent limitations for suspended solids. This subject has been under study by the Resource Extraction and Handling Division of the Industrial Environmental Research Laboratory which may be contacted for further information.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This document presents findings of a study to determine methods to improve the performance of surface mine sediment basins. During the course of this study, two methods were investigated: physical and chemical. Physical additions to sediment basins were investigated in an attempt to approach optimum removal potential. Various modifications have been delineated including inlet and outlet redesign along with additions to the body of the pond. It is obvious that even under ideal conditions very small particles will not be removed by conventional sediment basins. It is because of this fact that the use of coagulants has also been studied for small particle removal.

This report was submitted in partial fulfillment of Contract No. 68-03-2677 by Skelly and Loy under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 1978 to February 1979, and work was completed as of October 19, 1979.

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Project officers for the U.S. Environmental Protection Agency during the past year were Ronald D. Hill and Roger C. Wilmoth. A special thanks to James Kennedy and the staff of the Crown Environmental Research Laboratory of the U.S. Environmental Protection Agency for their assistance throughout the project.

SECTION 1

INTRODUCTION

The control of erosion and sedimentation from disturbed lands is a subject of increasing interest, particularly in the area of surface mining. Given the hydrologic conditions and the steep sloped terrain of the Appalachian coal region, it is understandable that erosion is a severe problem for surface coal mine operators. Current sediment control technology in this industry is primarily in the use of sedimentation ponds.

A study of the regulatory design criteria has shown that coal surface mine sedimentation ponds are generally designed based on two parameters: 1) provide a specific required storage capacity depending upon the amount of disturbed area in the contributing watershed; and 2) provide a required storage capacity to retain the runoff from a particular storm event for a specified period of time. Where influent suspended solid loads are extremely high, a sedimentation pond could meet the design standards, yet the effluent may not be of acceptable quality. Since many states and the Federal government are currently adopting water quality criteria which include the regulation of suspended solids concentration in the effluent, it would appear that the design of sedimentation basins should consider the pond's ability to achieve a specific effluent quality.

A serious problem relating to the achievement of a specific effluent quality, namely suspended solids limitations, relates to the amount of small particulate matter present in the influent to the basin. Disturbance of this material during active mining operations leads to erosion and introduction of an approximately colloidal size suspended solids fraction in the pond influent. Conventional settling procedures will not permit these particles to settle out of suspension; therefore, new procedures must be employed to remove this colloidal fraction. Two methods of achieving this goal have been investigated during this study; physical modifications to existing sediment pond configurations, and the use of chemical coagulants to cause the colloidal particles to agglomerate and settle in a mass. During the course of this study, six representative sediment ponds throughout the Appalachian coal fields have been observed to determine possible improvements to their design in conjunction with laboratory testing of a wet-weather sediment-laden influent sample from each pond. This wet-weather water sample was collected during a moderate rainfall event and was later subjected to a series of bench scale treatability tests to determine the applicability of a group of selected chemical coagulants. Through separate sections of the subsequent text, the results of these studies are discussed.

SECTION 2

CONCLUSIONS

Current design criteria for sedimentation basins are based upon the amount of disturbed area in the drainage area of the pond and/or the retention of runoff from a particular storm event for a specified period of time.

According to the theory of sedimentation, several interrelated factors have a substantial effect on the performance of a settling basin:

- Water temperature;
- Characteristics of the particle to be removed;

    Specific gravity
    Size
    Shape
    Aggregation

- Flow rate of drainage into and through the pond;
- Depth;
- Surface area of the pond; and
- Non-ideal conditions in pond;

    Short circuiting
    Turbulence
    Scouring.

- Colloidal-size particles will not settle from solution within normal detention times.

- Colloids remain in solution and resist the forces of gravity because of their extremely small size, chemical combination with water, or surface electrical charge.

- Three general types of sediment ponds are used in Appalachia:

    - Excavated sediment ponds;
    - Excavated sediment dams; and
    - Embankment sediment ponds.

- The laboratory tests indicated the presence of settleable solids in the effluent of each sediment pond studied.

- All model sediment ponds, except KY-1, complied with the effluent limitations for suspended solids during the sampling period. All ponds, except KY-1, exhibited greater than 90% removal during the sampling period.

- According to theoretical analysis, none of the model sediment ponds would meet effluent limitations for suspended solids during the passage of a 10-year 24-hour storm.

- Physical modifications to a sediment pond may be made in three areas:

  - Inlet;
  - Pond Body; and
  - Outlet.

- Inlet modifications are undertaken with three objects in mind:

  - Dissipation of energy of influent;
  - Distribution of influent over the entire width of the pond to maximize use of the cross-sectional area; and
  - Filtration of the influent.

- Pond configuration modifications are limited to two basic concepts;

  - Compartmentalization of the basin to induce staged settling; and
  - Size, shape, and depth modifications.

- Outlet Modifications include:

  - Changes to standard riser barrels;
  - Flared exit channels;
  - Baffle outlets; and
  - Vegetative filters.

- During the laboratory testing phase of this study, cationic coagulants were generally more effective in the removal of suspended solids than anionic coagulants.

- Optimum coagulant dosage varies with characteristics of the subject water but will generally increase with the colloidal suspended solids concentration.

- The suspended solids removal at 4 C was generally less efficient than that at 21 C.

- The environmental impact of coagulant usage for suspended solids removal would be minimal.

- Based upon a flow rate of 0.0283 m /sec (1 cfs), the daily cost (chemical purchase only) for the seven best coagulants tested would range from $6.42 - $40.68.

SECTION 3

RECOMMENDATIONS

- Phase II and Phase III of the study should be undertaken to demonstrate the effect of physical modification alternatives on sedimentation basin performance and the technical and economic feasibility of the usage of coagulants for suspended solids removal.

- The coagulants to be used in Phase III demonstration will be one of the two best performing coagulants in the bench-scale treatability tests:

    - American Cyanamid - Magnifloc 587C
    - Calgon Corporation - M-502

- Phase III demonstration should take place in at least two diverse geographic areas. One area to represent the steep topography of the Appalachian region and one to represent the rolling topography of the midwest/western region.

- Surface mine sedimentation basin design criteria should consider the following:

    - A sedimentation volume to settle particles of a specified size depending upon the influent particle size distribution
    - Sludge storage capacity
    - Detention storage capacity for the runoff from a specified storm event

- Whenever possible, sediment control methods should be used as close to the point of sediment origin as is feasible.

- To compensate for non-ideality of sediment basins, physical modifications to the basin should be utilized as detailed in the section of this study which discusses physical modification alternatives.

- When the influent particle size distribution contains high percentages in the silt-clay range, chemical coagulants should be used to achieve sufficient suspended solids removal in order to comply with the effluent limitations.

SECTION 4

THEORY OF SUSPENDED SOLIDS REMOVAL

The removal of suspended solids from a liquid medium has been a subject of study for engineers during the past two hundred years. Generally speaking, there are two basic methods of suspended solids removal-physical straining processes and gravity separation. Physical straining is the removal of suspended solids by mechanical filtration while gravity separation refers to suspended solids removal by taking advantage of gravitational forces on the particles. The processes of physical straining are not discussed here because of the inapplicability of this technique to surface mine drainage. The principles of gravity separation are discussed in two subsequent sections, Sedimentation and Coagulation. A discussion of the theory of sedimentation and coagulation is necessary to lay the groundwork for an understanding of the practical aspects of sediment pond design. Without a basic comprehension of the principles of sedimentation, one will not be able to offer criticism of existing sediment pond construction techniques nor develop methods to improve their performance.

SEDIMENTATION

Sedimentation is a natural sequence of events involving erosion, entrainment, transportation, deposition and compaction of particulate matter in water. Deposition or settling is concieved as a gravitational process. On the basis of concentration and particle interaction, four general classifications of settling have been determined:

1) Free Settling;
2) Flocculant Settling;
3) Zone Settling; and
4) Compression Settling.

Of primary interest to this discussion is free settling, which is described mathematically under ideal conditions by Stoke's Law and is the basis for suspended solids removal by gravitational settling. It has been shown that when a particle is present in a liquid, the particle will move in a verticle direction due to gravity forces, accelerating until a constant velocity is attained. This constant velocity is known as the settling velocity of the particle and is dependent upon the density, size and shape of the particle and the viscosity of the fluid, which is strongly temperature dependent.

$V_s = g/18\mu \; (P_p - P_w) \; D^2$

V_s = Terminal Settling Velocity, cm/sec

g = Acceleration due to gravity, 981 cm/sec^2

μ = Water viscosity, poise (temperature dependent)

P_w = Water density, g/cm^3

P_p = Particle density, g/cm^3

D = Particle diameter, cm

As can be seen from the variables in the above formula, the settling velocity of a particle is dependent upon the temperature of the water it is carried in, the specific gravity of the particle itself, and the shape of the particle (spherical, flat, or rod-shaped). Table 1 shows the effect of water temperature on settling velocity using room temperature (20° C) as a standard. The changes in settling velocity were computed by Stoke's Law, varying the viscosity of water at different temperatures and holding all other variables constant.

TABLE 1. EFFECT OF WATER TEMPERATURE ON SETTLING VELOCITY[1]

Temperature °C	Change in settling velocity (percent)
0°	-44
10°	-23
20°	0
30°	+26

Specific gravity is also a factor which may vary widely. For example, the specific gravity for most soil particles is assumed to be 2.65; however, the specific gravity of coal particles will range from 1.29-1.32. Finally, the shape of the particle will affect the settling velocity. Experimental data on the settling velocity of nonspherical particles indicates that a rod-shaped particle will have a settling velocity that is 73- 78% of a spherical particle. The range of settling velocities, for particle sizes according to gradation of sand, silt and clay size spheres in water at various temperatures, is shown in Table 2.

Sedimentation basin design is based upon the theory that all particles having a settling velocity greater than or equal to the design settling velocity will be removed prior to exiting the basin. Figure 1 indicates this settling velocity relation. The settling velocity of a particle that would be just removed ($V_y = V_s$) can be related to the depth of the tank and the retention time as follows:

TABLE 2. SETTLING VELOCITIES OF SEDIMENT IN WATER[2]

Diameter of particle			Classification	Terminal settling velocity		
Micron	cm	mm		@ 0°C	@ 10°C	@20°C
10,000	1	10	Gravel	5027 cm/sec (165) ft/sec	6874 (225)	8975 (294)
1000	0.1	1	Coarse sand	50. (1.65)	68.7 (2.25)	89.8 (2.94)
1000	0.01	0.1	Fine sand	0.50 (0.017)	0.69 (0.023)	0.90 (0.029)
10	0.001	0.01	Silt	0.005 (1.6×10^{-4})	0.0069 (2.3×10^{-4})	0.009 (2.9×10^{-4})
1	0.0001	0.001	Clay	5.03×10^{-5} (1.6×10^{-6})	6.87×10^{-5} (2.3×10^{-6})	8.98×10^{-5} (2.9×10^{-6})
0.45	0.000045	0.00045	Clay	1.02×10^{-5} (3.34×10^{-7})	1.39×10^{-5} (4.57×10^{-7})	1.82×10^{-5} (5.9×10^{-7})
0.10	0.00001	0.0001	Colloid	5.03×10^{-7} (1.6×10^{-8})	6.87×10^{-7} (2.3×10^{-8})	8.98×10^{-7} (2.9×10^{-8})

*Conditions:	Temperature, °C	0°	10°	20°
μ =	Water viscosity, poise	0.01787	0.01307	0.01002
Pw =	Water density, g/cm^3	0.99987	0.99973	0.99823
Pp =	Particle density, g/cm^3	2.65	2.65	2.65
g =	Gravitational constant, cm/sec^2	981	981	981
D =	Particle Diameter, cm	variable	variable	variable

$$V_s = \frac{h}{t} \quad \frac{\text{Depth of pond at outlet zone}}{\text{Time the particle is in the pond (detention time)}}$$

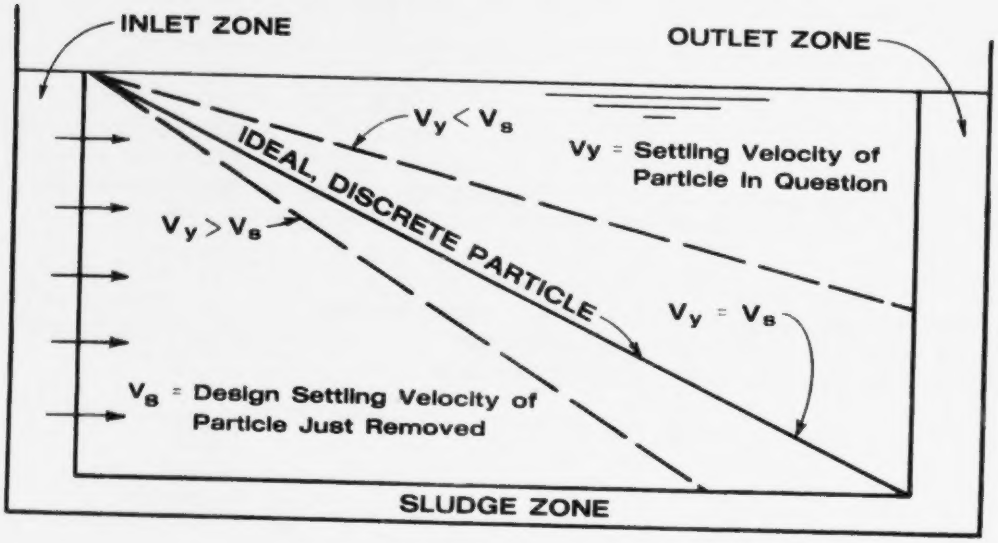

INLET ZONE
OUTLET ZONE
$V_y < V_s$
V_y = Settling Velocity of Particle In Question
IDEAL, DISCRETE PARTICLE
$V_y > V_s$
$V_y = V_s$
V_s = Design Settling Velocity of Particle Just Removed
SLUDGE ZONE

Figure 1. Discrete particle settling.[3]

Under constant flow - ideal conditions, the time that the particle is in the pond may be calculated as follows:

$$\text{Time} = \frac{\text{Volume of pond}}{\text{Flow rate of drainage}} = \frac{hA}{Q}$$

A = Surface area of pond
Q = Inflow to pond

By combining the two previous equations, it can now be seen that the settling velocity of a particle just removed, in a particular ideal sedimentation basin, is related to the inflow rate and basin size as follows:

$$V_s = \frac{Q}{A} = \frac{\text{Flow rate of drainage into the pond}}{\text{Surface area of pond}} = \frac{m^3/\text{sec}}{m^2} = m/\text{sec}$$

The above relationship indicates that surface area of a sediment pond ideally has a substantial effect on the removal efficiency. This effect is illustrated by the data in the following table, which shows the minimum surface area required to settle particles of selected size for a $0.0283 m^3$/ sec (1 cfs) outflow.

TABLE 3. MINIMUM SEDIMENT POND AREA REQUIREMENTS TO SETTLE PARTICLES OF SELECTED SIZES[4]

Particle diameter (millimeters)	Minimum area required m^2	ft^2
0.06	7.43	80
0.04	13.5	145
0.01	189	2030 (0.046 acres)
0.001	18,900	203,000 (4.6 acres)
0.0001	1,890,000	20,300,000 (466 acres)

This value of settling velocity is also known as the surface hydraulic loading or overflow rate. Hazen showed that the removal efficiency of a basin is solely dependent on hydraulic loading (ideal settling) when the following assumptions are true:[5]

1. Flow through the basin is quiescent.

2. Horizontal flow-through velocity is distributed uniformly through a cross-section of the basin.

3. Suspended particles are discrete and non-interacting.

4. Once the particles settle out, they do not become resuspended.

If the preceding conditions hold true, theoretically 100% of the particles having a settling velocity greater than or equal to the design settling velocity will be removed; however, as is the case more often than not, conditions in actual sedimentation ponds do not follow theory. Among the changes from theory occurring in many actual ponds are:

1. Short-circuiting due to currents within the pond.

2. Turbulence, due to flow-through velocity, retards settling.

3. Sludge may be scoured and resuspended at high flow-through velocities.

Short-circuiting, the flow of water directly through a pond from inlet to outlet in straight-line fashion, may have a great effect on the removal efficiency of a sedimentation basin. The short-circuiting can be caused by high inlet velocities, high outlet flow rates, location of inlets and outlets in close proximity to one another, exposure of surface area to strong winds, uneven heating of basin by sunlight, and density differences between influent solids concentration and basin solids concentration. Inlet and outlet conditions and basin geometry are factors which cause steady short-circuiting while the other causes are intermittent. Using salt tracer studies on four types of settling tanks, short-circuiting was minimized in narrow, rectangular, horizontal-flow tanks when short-circuiting was due primarily to inlet and outlet conditions and tank geometry. The most important considerations in the attempt to minimize short-circuiting are dissipation of inlet velocity, location of inlet and outlet structures relative to one another, and the reduction of outflow velocity.

Research by Camp conducted on settling tanks of various shapes and sizes has led to a short-circuiting compensation factor (F_{sc}) for basin geometry that diverges from the ideal as shown in Table 4. To compensate for the non-ideality of a settling basin, the design surface area for an actual pond should be increased as follows:

$$A = (F_{sc} \times \frac{Q}{V_s})$$

Q = Flow, m^3/sec
V = Design Settling Velocity (m/sec)
F_{sc} = Short-circuiting factor

TABLE 4. SHORT-CIRCUITING FACTORS FOR SETTLING TANKS[6]

Type of tank	Short-circuiting factor (Fsc)
Radial-flow circular	1.2
Wide rectangular (length = 2.4 x width)	1.18
Narrow rectangular (length = 17 x width)	1.11
Baffled mixing chamber (length = 528 x width)	1.01
Ideal basin	1.0

Turbulence in a settling basin can be minimized by designing the basin to lessen the causes of turbulence, such as inlet, outlet, wind, and density currents. The horizontal flow-through velocity of a pond causes turbulence which will affect any particles which have a settling velocity approximately equal to the overflow velocity. Figure 2 depicts the trap efficiency of a reservoir vs the ratio of settling velocity to overflow velocity for turbulent conditions.

Scouring of settled sludge material refers to the resuspension of sediment previously settled from solution by a high horizontal current velocity in the pond. Scour velocity is described as that velocity of

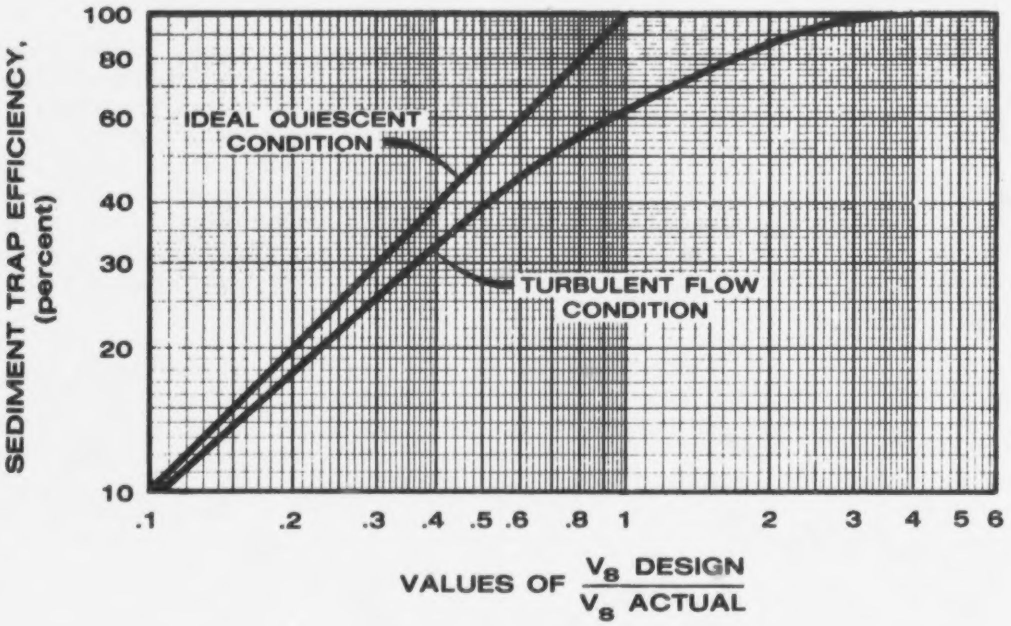


Figure 2. Determination of trap efficiency.[7]

flow required to start in motion a free unattached particle of a specific size. The formula to compute scour velocity is as follows:

$V_c = \sqrt{\frac{8B}{F} g(S-1)D}$;
V_c = Scour velocity in cm/sec;
B = Shield's Critical Shear Stress Parameter, .04 for uniform sand, .06 for cohesive material;
g = Acceleration due to gravity, 981 cm/sec^2;
S = Specific gravity of particle;
D = Diameter of spherical particle (cm); and
F = Darcy-Weisbach friction factor, usually .02-.03.

In order to retain the settled particles within the basin, the horizontal velocity should be maintained at less than the scour velocity.

As detailed by the previous discussion on the theory of sedimentation, several interrelated factors have a substantial effect on the performance of a settling basin:

- Water temperature;

- Characteristics of the particle to be removed:

  - Specific gravity;
  - Diameter (size);
  - Shape;
  - Aggregation;

- Variation in flow rate of drainage into and through the pond;
- Surface area of the pond;
- Depth; and
- Non-ideal conditions in pond
    - Short-circuiting
    - Turbulence
    - Scouring.

In the process of designing a settling basin, one must take care to consider all the variables having an effect on sedimentation.

COAGULATION

When suspended particles in water approach a very small size, less than .001 mm, they are non-settleable and are described as colloidal dispersions. Colloidal dispersions consist of discrete particles that remain in suspension because of their extremely small size, chemical combination with water, or surface electrical charge. The size of the particle is an important factor in keeping the colloid in suspension because larger particles have a lower surface area to mass ratio and consequently are more affected by gravity forces causing sedimentation. With colloids, the surface area to mass ratio is high and surface forces such as electrostatic repulsion and chemical combination with water predominate over the forces of gravity. Figure 3 displays the classification of particles by size.

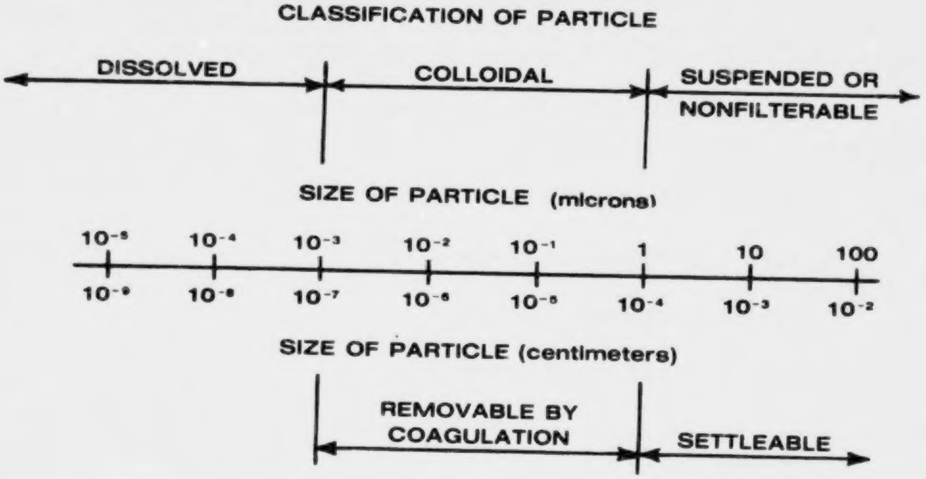

CLASSIFICATION OF PARTICLE
DISSOLVED
COLLOIDAL
SUSPENDED OR NONFILTERABLE
SIZE OF PARTICLE (microns)
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
100
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
SIZE OF PARTICLE (centimeters)
REMOVABLE BY COAGULATION
SETTLEABLE

Figure 3. Classification and size range of particles found in water.[8]

Colloidal dispersions can be subdivided into two types, hydrophilic and hydrophobic. Hydrophilic colloids are stable in suspension due to their affinity for water, while hydrophobic colloids have no affinity for water and are stable because of their electric charge. The hydrophobic colloid becomes charged by adsorbing positive ions from the water solution. The layer of positive relatively non-exchangeable ions known as the Stern layer is attracted to the negatively charged particle. The Stern layer is then surrounded by a moveable, diffuse layer of counter ions. The concentration of positive ions in this diffuse layer decreases as the distance from the central particle increases. Figure 4 depicts the electric potential of the diffuse layer of counter ions and the Stern layer. The electric potential increases from zero at the outer edge of the counter ion layer to its maximum at the surface of the particle. The Zeta potential of the particle is the magnitude of this charge at the surface of shear between the Stern layer and the diffuse layer of counter ions and can be estimated from electrophoretic measurement of particle mobility in an electric field.

When a high zeta potential exists, a stable colloidal dispersion exists, i.e., the individual particles do not tend to aggregate because of the repulsive forces of the double layer of ions surrounding each particle. Removal of colloids from solution or destabilization of the colloidal dispersion can be accomplished by the addition of electrolytes. The electrolytes which are most effective in destabilization are multi-valent ions with an opposite charge to the colloidal particles. Oppositely charged counter ions of the electrolyte decrease the double layer colloidal charge to a point where particle contact is made and Van der Waal's forces of attraction cause the particles to aggregate. Another method of destabilization is the bridging of particles with long chain organic polyelectrolytes. The polyelectrolyte attaches to surfaces of colloidal particles causing a bridging effect, forming a larger particle. A third destabilizing agent is a hydrolyzed metal ion which acts both in compression of the double layer and in bridging of the particles.

The removal of colloidal particles from solution using coagulants depends upon several factors:

- nature and concentration of colloid;
- type and dosage of coagulant;
- use of coagulant aid; and
- characteristics of water
  - pH
  - temperature
  - ionic character.

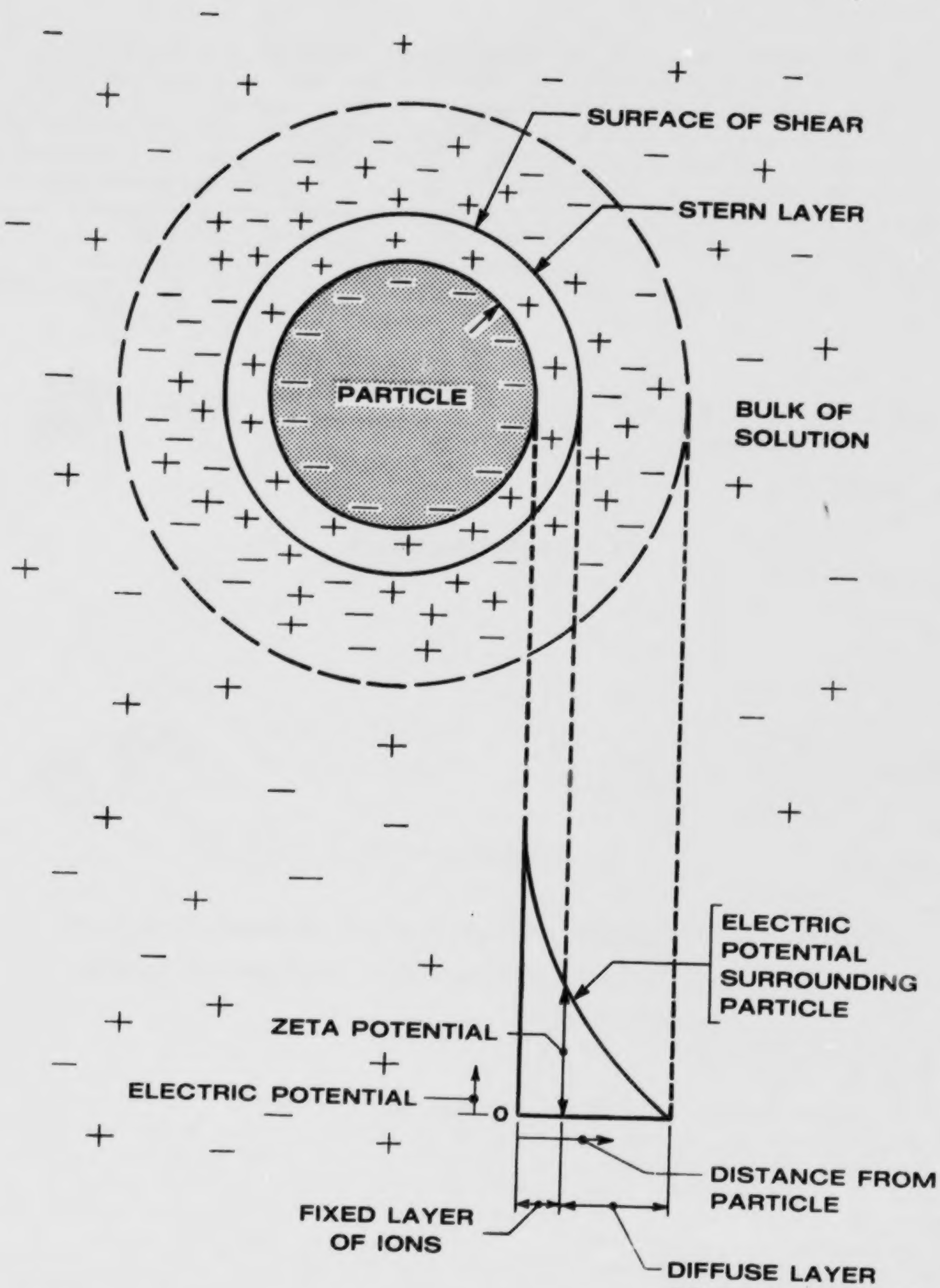
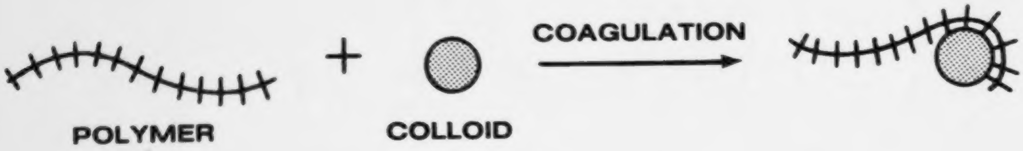
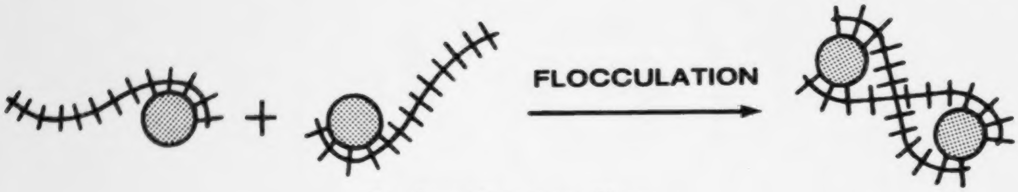

SURFACE OF SHEAR
STERN LAYER
PARTICLE
BULK OF SOLUTION
ELECTRIC POTENTIAL SURROUNDING PARTICLE
ZETA POTENTIAL
ELECTRIC POTENTIAL
0
DISTANCE FROM PARTICLE
FIXED LAYER OF IONS
DIFFUSE LAYER OF COUNTER IONS

Figure 4. Concept of zeta potential derived from the diffuse double layer theory.[9]

Due to the complex nature of the chemistry of colloidal destabilization, the chemical treatment of water is usually based upon empirical data derived from laboratory treatability tests. In the treatment of colloids, the term coagulation is generally used to describe the complete process of colloid removal as depicted in Figure 5. This process generally includes two separate phases: 1) chemical addition and mixing during which the coagulant is added to the water and dispersed, usually by violent agitation, and 2) flocculation, occurring for a much longer period of time, during which the water is slowly mixed and the particles are allowed to agglomerate to form larger settleable particles.



A. Destabilization



B. Agglomeration

Figure 5. Colloidal suspension destabilization with high molecular weight organic polymers.[10]

The removal of suspended solids by coagulation is a point of great interest due to the requirements of the 1977 Clean Water Act specifying a limit of total suspended solids permitted in the effluent of a surface mine sediment basin. Many existing basins will not be able to meet the specified effluent limitations because of the particle size distribution of the influent suspended solids. If the total amount of particles contains high percentages in the non-settleable range, then the process of coagulation must be used for their removal in order to comply with existing regulations.

SECTION 5

DISCUSSION OF STUDY FINDINGS

During the course of this study, the project was essentially divided into three separate phases:

- Selection and evaluation of model sediment ponds;
- Evaluation of physical modification alternatives; and
- Evaluation of the use and applicability of coagulants to improve sedimentation pond performance.

SELECTION AND EVALUATION OF MODEL SEDIMENT PONDS

In the construction of sediment ponds, the surface mine operator has the option to choose among three basic variations of design. The first and most basic of the three is the excavated sediment pond or "dug-out" as depicted in Figure 6. An excavated sediment pond is essentially a hole in the ground which acts as a sump. The water flows into the excavated pond at one end and overflows the downstream end with no construction of detailed inlet and outlet devices. The excavated pond is easily constructed by backhoe or dozer. As is evident by the limited use of this technique, it is only applicable in certain specific situations such as the treatment of runoff from a small area or from an area with relatively flat terrain.

The second type of sediment pond is known in West Virginia as the sediment dam, excavated type. With this type of pond, an embankment is constructed in association with the excavation for additional storage capacity. The principal and emergency spillway are combined as an exit channel through the embankment as shown in Figure 7. The one specific requirement is that the minimum outflow elevation through this spillway be less than three feet above natural ground, in which case no more than three feet of water will be impounded without discharge through the outlet. This method is used widely throughout West Virginia because of it's ease of construction and limited cost.

The third method of construction also uses an embankment, but makes use of a pipe and riser barrel for a principal spillway, with an excavated emergency spillway in natural ground as seen in Figure 8. By the

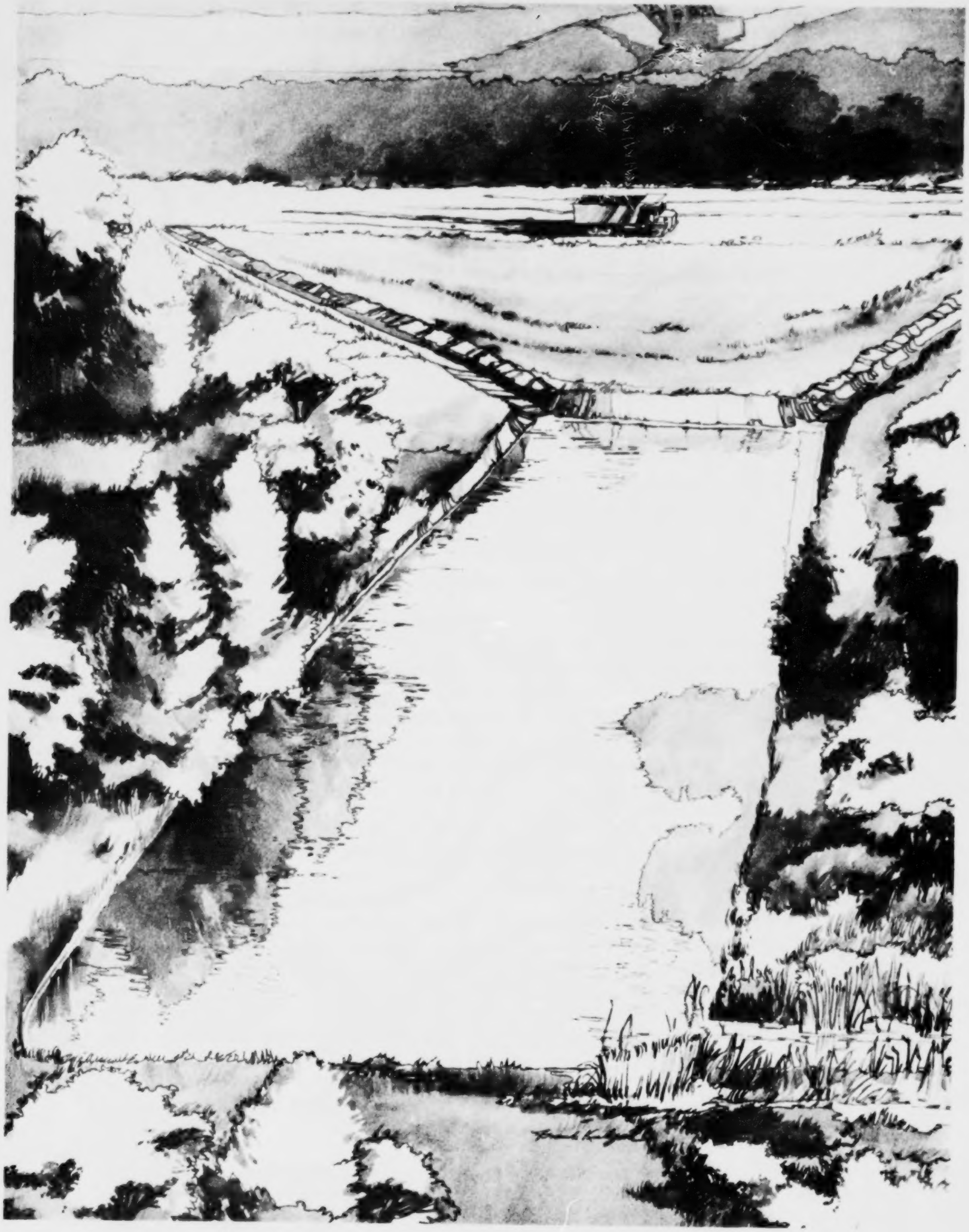


Figure 6. Excavated sediment pond.

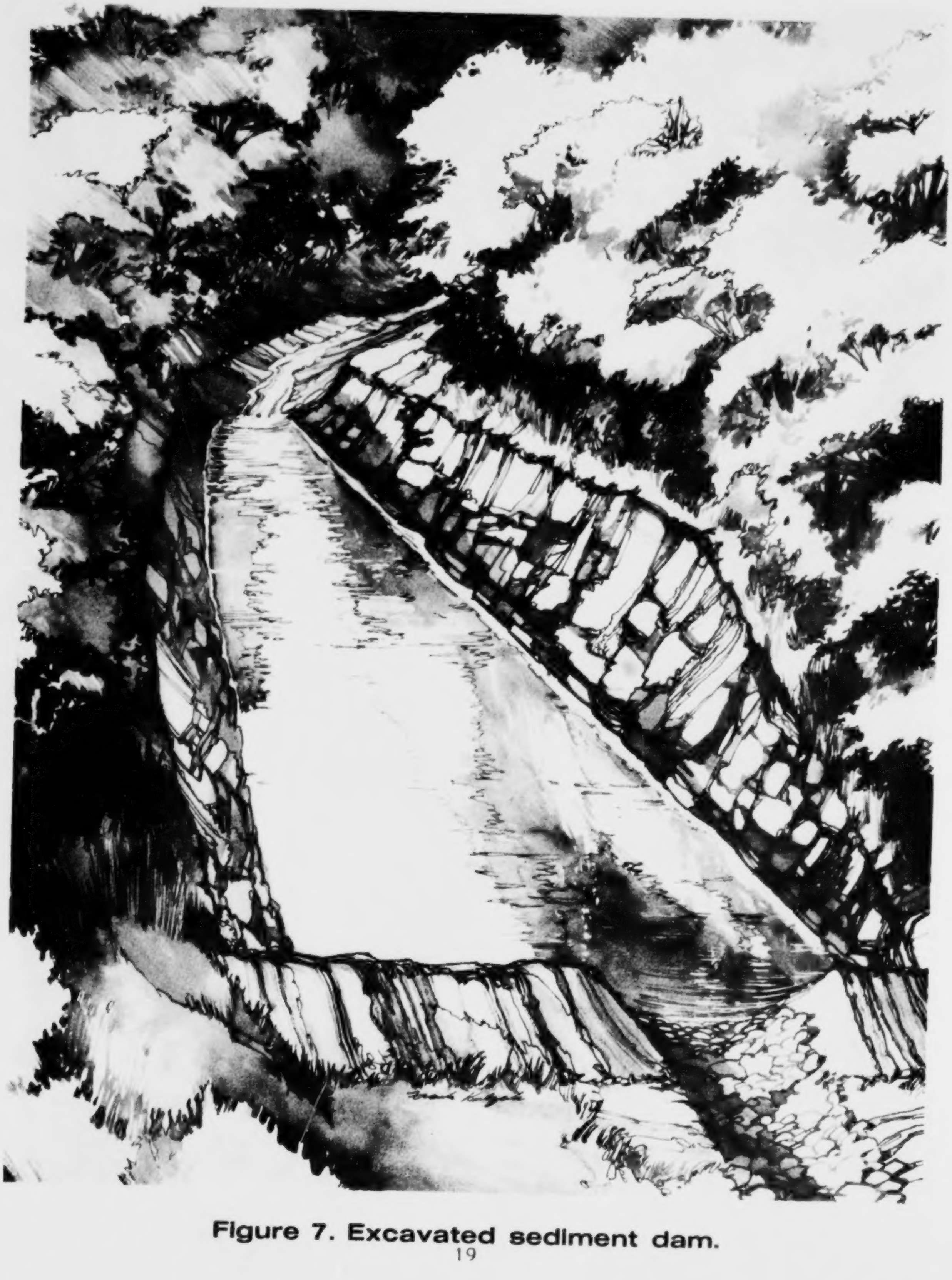


Figure 7. Excavated sediment dam.

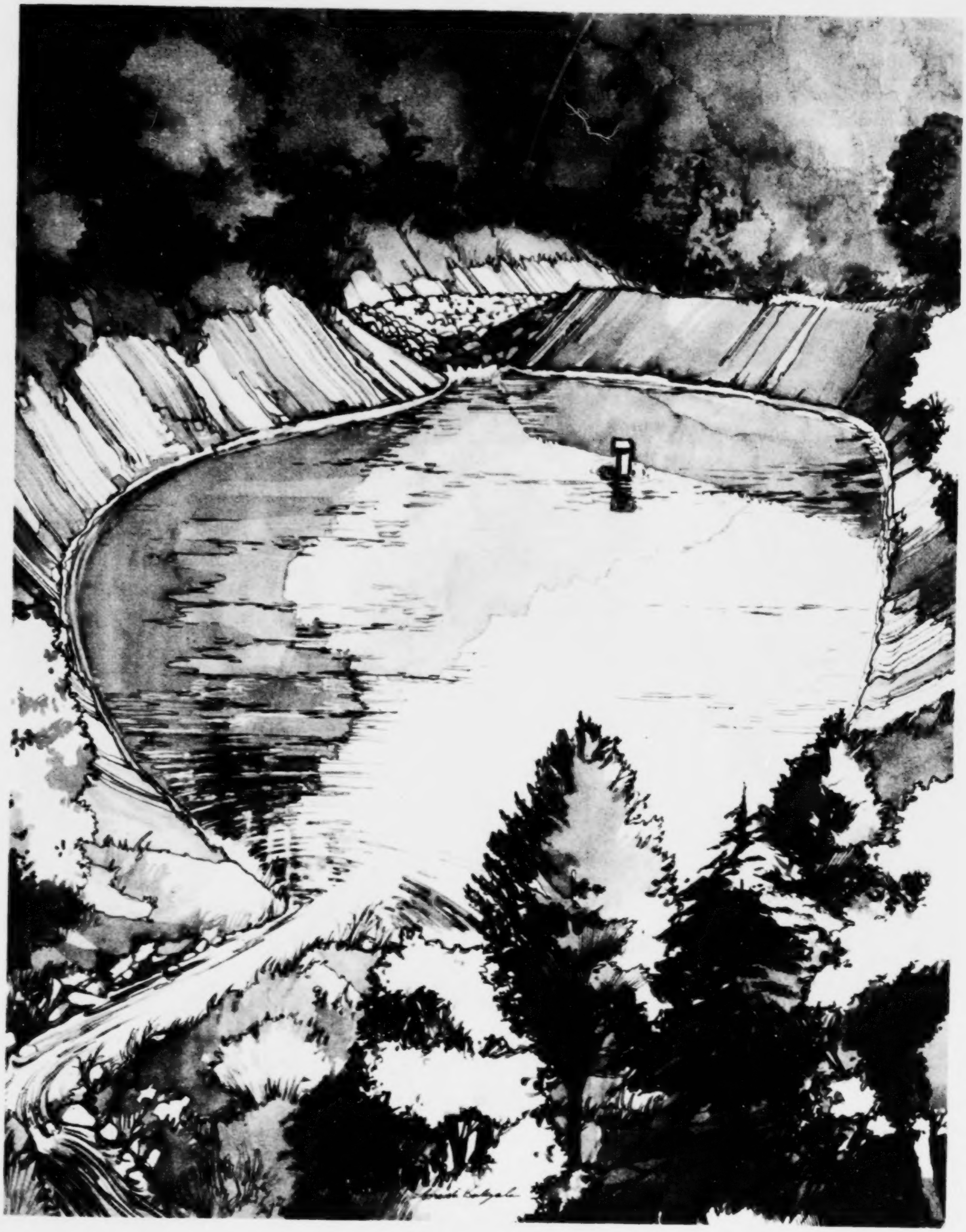


Figure 8. Embankment sediment pond.

use of this method in conjunction with excavation, a much larger storage capacity can be attained. Because of the required size of many sedimentation ponds, a large number of surface mine operators use this method.

Six "model" sediment ponds were chosen as the basis of this study to represent the methods currently used for sediment removal in the Appalachian coal fields. These six ponds served as the sources of sediment-laden influent upon which bench-scale coagulant testing was performed, as will be discussed in depth later, and as examples of the various physical design characteristics used in the study area. The geographic locations of the sediment ponds are as follows: southwestern Pennsylvania, PA-1; northeastern West Virginia, WV-3; central West Virginia, WV-4; two ponds located in southwestern West Virginia, WV-1 and WV-2; and one located in southeastern Kentucky, KY-1 (see Figure 9).

Physical Characteristics of Model Ponds

A field visit to each model sediment pond was arranged to gather data on the physical characteristics and to obtain an influent and effluent water sample during wet-weather flow conditions. The method of physical data gathering was of a reconnaissance nature and as such was rather general in scope. The physical measurements and observations made at each location were as follows:

- general description and location;
- description and measurement of inlet area;
- measurement of pond size;
- shape of pond;
- description and measurement of outlet area; and
- general condition of the pond.

Additional data was gathered from the design plans for each pond concerning items such as drainage area, disturbed area contributing to the pond, and general design computations. Throughout the next section, physical characteristics of each model pond are listed and discussed.

Southwestern Pennsylvania PA-1--

Sediment pond PA-1 is typical of the technique used to control sediment from surface mines in Pennsylvania. In that state, most of the runoff from the affected area of a mine is directed into the pit. From the pit, it is pumped, along with active mine drainage generated within the pit, to a series of treatment ponds for neutralization and settling. Through the use of storage and preliminary settling in the pit, the operator minimizes the sediment pond storage requirements. Finally, if it is

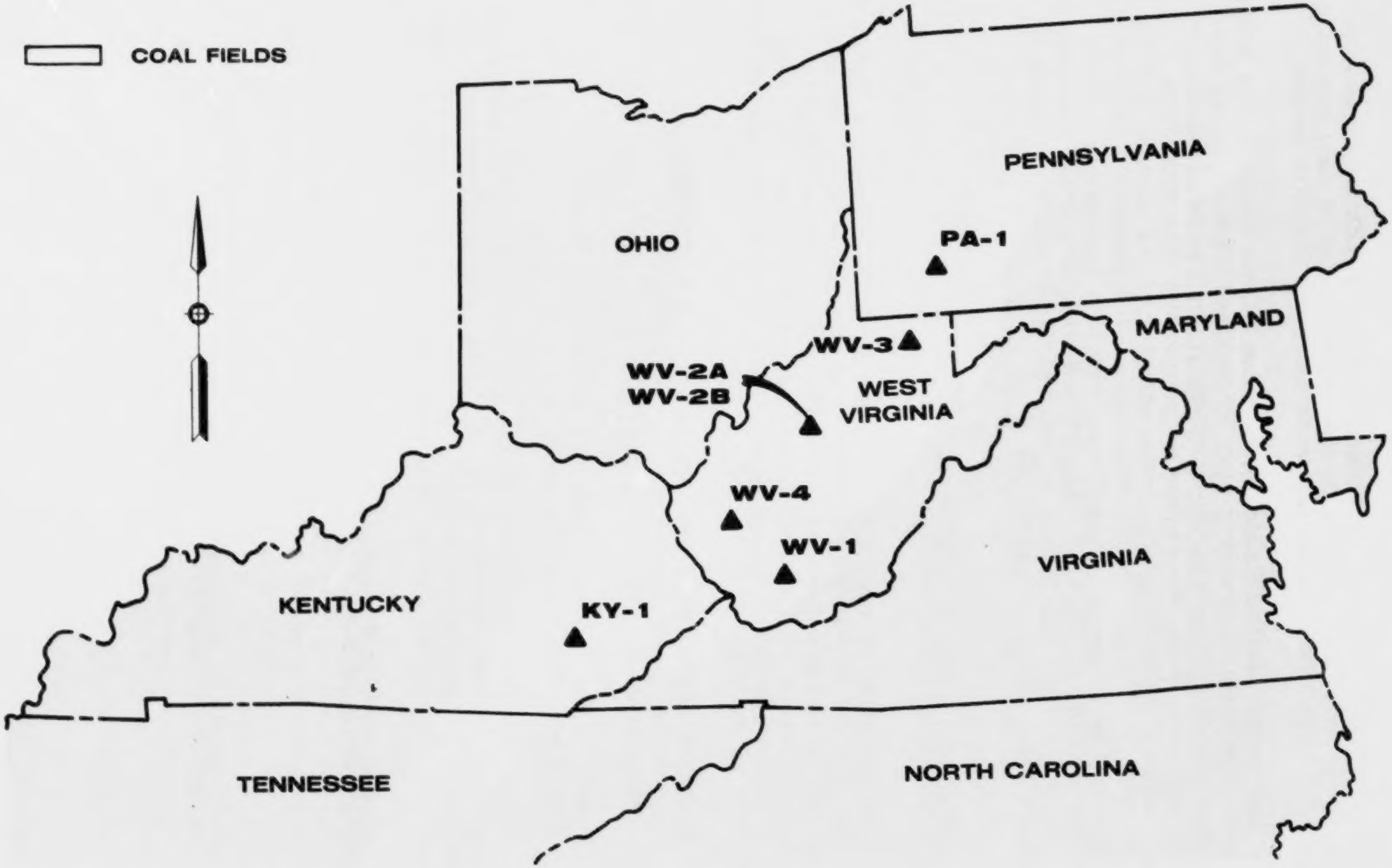

COAL FIELDS
PENNSYLVANIA
OHIO
PA-1
MARYLAND
WV-3
WV-2A
WV-2B
WEST VIRGINIA
WV-4
WV-1
KENTUCKY
KY-1
VIRGINIA
TENNESSEE
NORTH CAROLINA

Figure 9. Location of model sediment ponds.

difficult to direct runoff from part of a disturbed area, such as a haul road, to the pit, a sediment pond will be constructed to treat the runoff from that small affected area. The pond is located out of a natural drainway to avoid collecting runoff from undisturbed areas, thereby lowering detention times by minimizing influent volume.

Sediment pond PA-1 is an excellent example of this type of pond. It is used to treat the runoff from a section of haul road directly above the pond. The pond is an excavated type (dugout) with a "flat lip" discharge which consists of a depressed area at one end of the pond. The pond's physical characteristics are detailed in Table 5.

Figure 10A is a photograph of sediment pond PA-1 showing the inlet area of the pond in the foreground and the body of the pond and the discharge in the background. Figure 10B is also a photograph of pond PA-1 with the inlet area in the foreground and the "flat-lip" discharge in the right background.

Southwestern West Virginia WV-1--

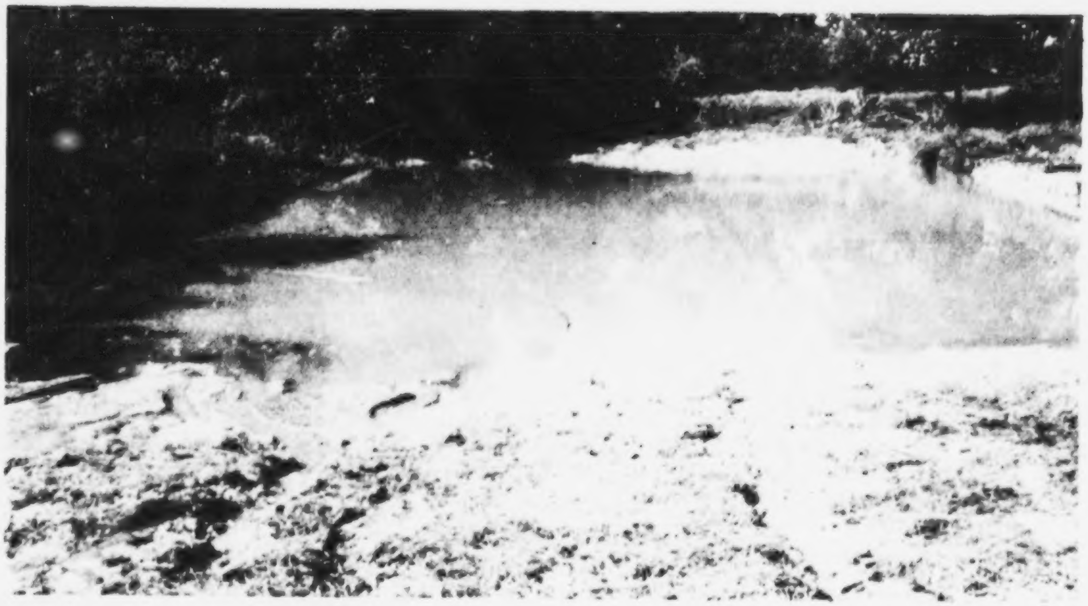
Sediment pond WV-1 is located in the southwestern section of West Virginia and is typical of the type of pond used in steep-sloped mining areas. These ponds are located directly in the major drainage system downstream of the mine site. The pond is constructed through a combination of excavation and embankment techniques. Use of this combination construction technique increases the storage capacity of the excavated pond. The additional storage is limited by West Virginia regulations to three feet above the original ground surface unless a principal pipe spillway and emergency spillway is included in the design. The spillway is generally a trapezoidal channel in the embankment with an invert elevation of three feet above the natural ground.

The volume of the West Virginia sediment pond is based upon the requirement of a 0.125 acre-foot per acre of disturbed area above the pond. This disturbed area in most cases consists of the face area of a valley fill since on-bench sediment control and valley fill construction techniques are practiced to limit the amount of sediment reaching the pond. Sediment pond WV-1's specific physical characteristics are listed in Table 6.

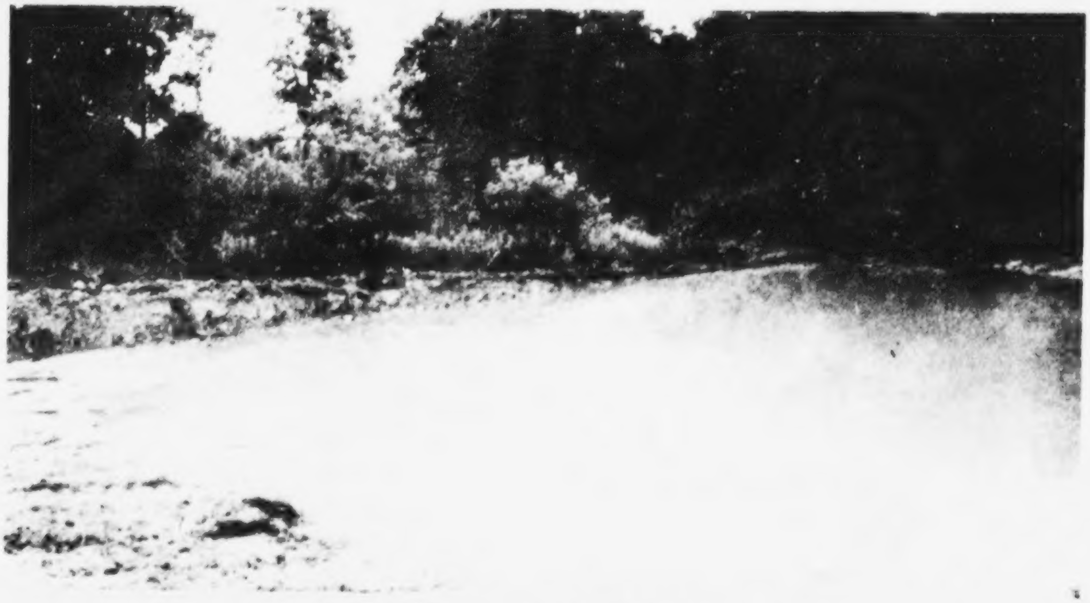
Figures 11A through 11C are photographs of the pond taken during the sampling period. Figure 11A is a photograph of the body of the pond taken from the embankment - note the swamp-like vegetation at the crest of the embankment. Figure 11B shows the entrance to the exit channel with vegetation growing in the body of the pond, and Figure 11C is a photograph of the concrete-lined exit channel.

TABLE 5. PHYSICAL CHARACTERISTICS-SEDIMENT POND PA-1

Physical characteristics	Description
Type	- Excavated Pond (dugout)
Location	- Off Main Drainage
Drainage Area	- Less than 12.1 hectares (30 acres)
Disturbed Area	- Less than 12.1 hectares (30 acres)
Inlet Configuration	- Random Inlet - No Defined Channel - No Erosion Control
Body of Pond	- Rectangular 35m x 23.6m (90 ft x 60 ft) - Depth 1.5m (5 ft) Verticle Side Slopes
Storage Volume	- 764.6m^3 (27,000 ft^3) (0.62 Acre-Ft)
Length : Width	- 1.5:1
Outlet Configuration	- "Flat-Lip" Discharge Depressed Swale at End of Pond Width = 5.2m (17 ft) Heavily Grassed, Clay, Swampy Material
General Condition of Pond	- No erosion control on inlet No erosion control on outlet Good general condition Appeared to be recently constructed



A. Main body of pond.



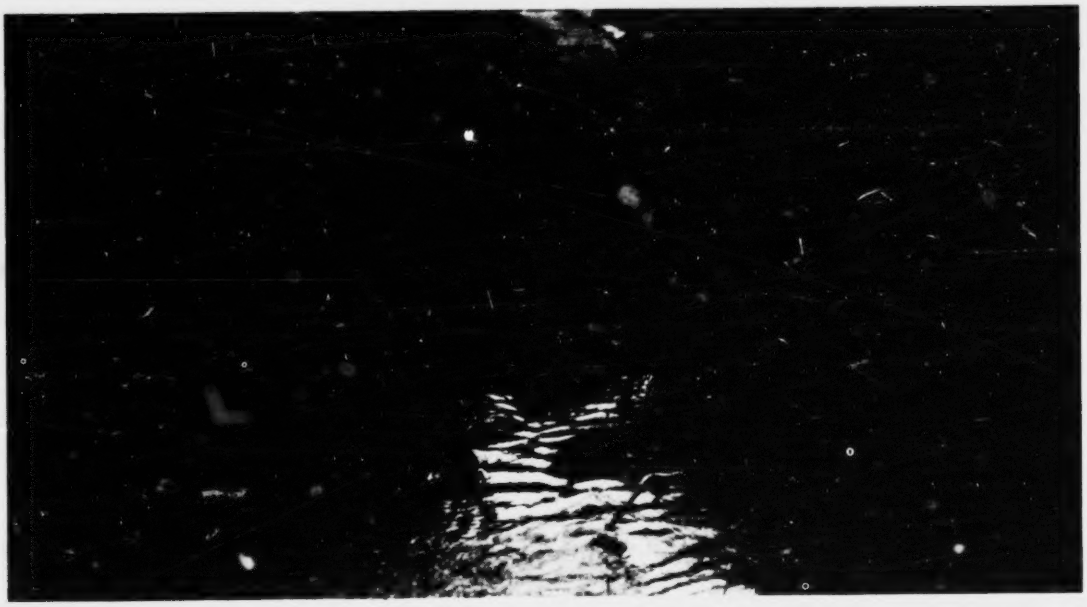
B. View of inlet area.

Figure 10. Sediment pond PA-1.

TABLE 6. PHYSICAL CHARACTERISTICS-SEDIMENT POND WV-1

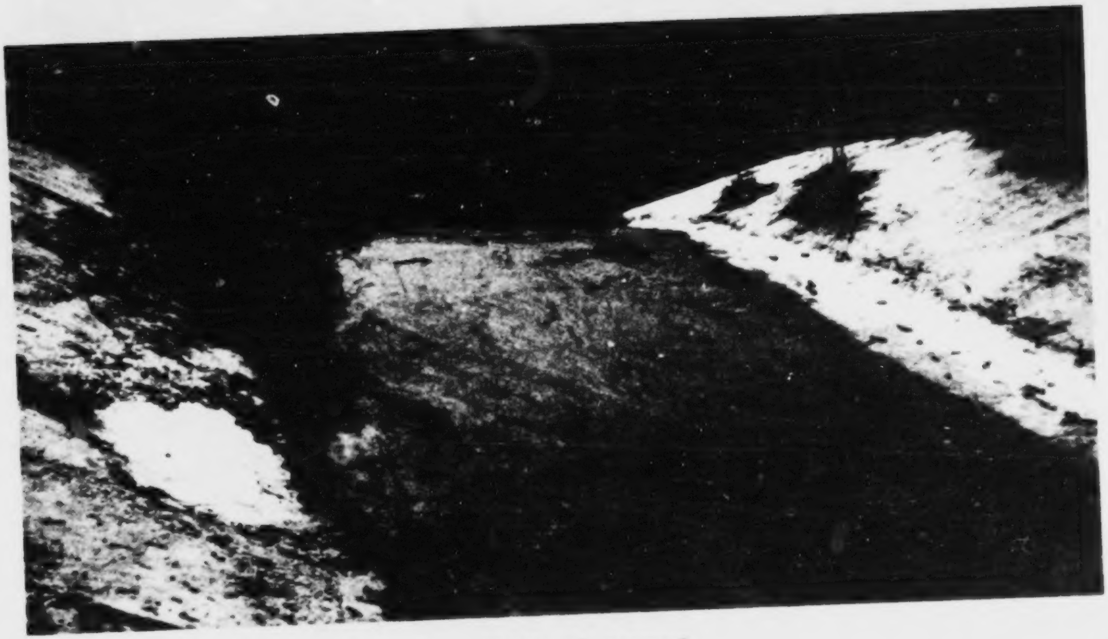
Physical characteristics	Description
Type	- Excavated Sediment Dam
Location	- On Main Drainage System
Drainage Area (Stream Watershed)	- 137.6 ha (340 Acres)
Disturbed Area	- 15.9 ha (64 Acres)
Inlet Configuration	- Trapezoid Concrete Lined 4.6m (15 ft) Bottom Width 6.7m (22 ft) Top Width 20% Slope
Body of Pond	- Pear Shaped 82.3m (270 ft) Long By 53.3m (175 ft) Wide at Embankment Approx. 1.5m (5 ft) Deep
Storage Volume	- 3330.8m^3 (2.7 AF)
Length : Width	- 1.5:1
Outlet Configuration	- Trapezoid Concrete Lined 4.6m (15 ft) Bottom Width 8.2m (27 ft) Top Width 20% Slope
General Condition of Pond	- At time of sampling, pond was choked with sediment. Vegetation had grown throughout 25% of the surface area.

A. View from embankment.



B. Top of exit channel.

Figure 11. Sediment pond WV-1.



C. Exit channel.

Figure 11. (continued)

Central West Virginia WV-2--

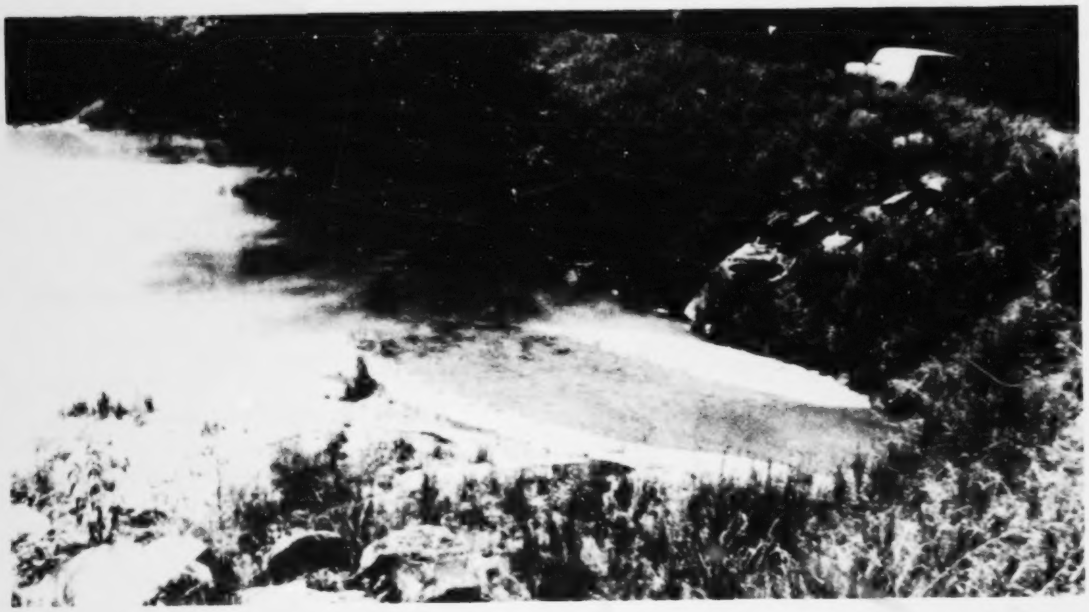
Sediment pond WV-2 is a combination of two ponds in a series, WV-2A and WV-2B. The first pond in the series is an excavated pond with an embankment similar to sediment pond WV-1. It is located in the natural stream channel and all drainage from the upstream area passes through the pond. Data on the pond's physical characteristics are listed in Table 7.

Figures 12A through 12C are photographs of pond WV-2A taken during a field visit to the mine site. The first figure indicates the inlet area to the pond where a delta of sediment has formed because of low influent velocity. Figure 12B shows the body of the pond and Figure 12C indicates the embankment with rock lined exit channel.

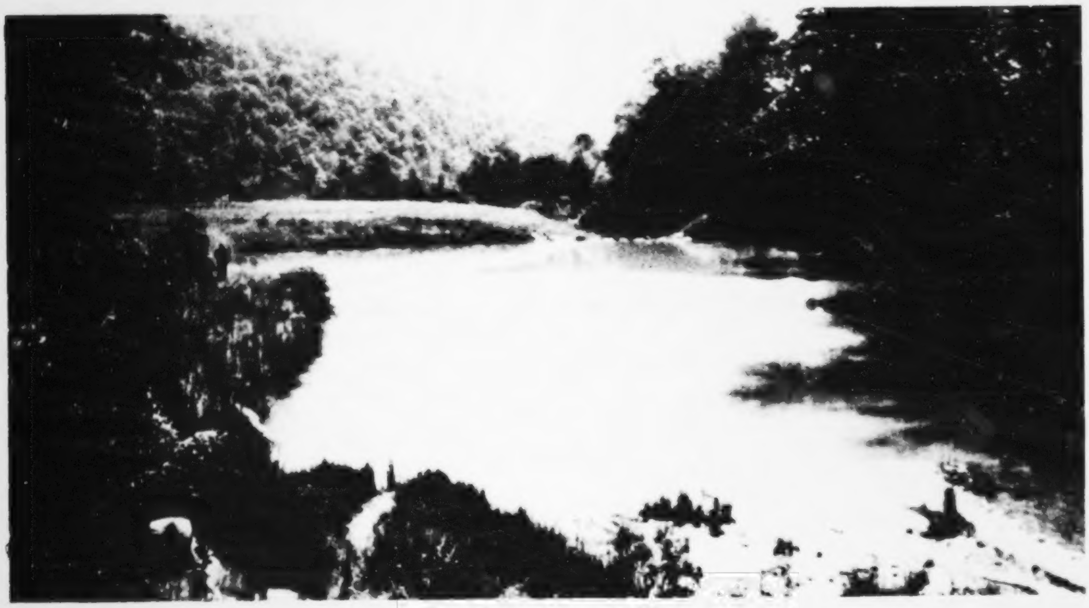
The second pond in this series is an excavated one approximately one kilometer downsteam from the first pond. It is located in an unusual position at the confluence of the original stream through the mine site and another drainage area. The pond is approximately rectangular in shape, 115.8m (380 ft) long by 45.7m (150 ft) wide. It has two rock lined trapezoidal entrance channels and a rock lined trapezoidal exit channel. Physical data for the pond are detailed in Table 8.

TABLE 7. PHYSICAL CHARACTERISTICS-SEDIMENT POND WV-2A

Physical characteristics	Description
Type	- Excavated Sediment Dam
Location	- On Main Drainage System
Drainage Area	- 174.4 ha (431 Acres)
Disturbed Area	- 18.6 ha (46 Acres)
Inlet Configuration	- Culvert Under Haul Road
Body of Pond	- Trapezoidal 109.7m (360 ft) Long 48.8m (160 ft) Wide at Dam 18.2m (60 ft) Wide at Upstream End
Storage Volume	- 5550 m^3 (4.5 AF)
Length : Width	- 3.3:1
Outlet Configuration	- Dumped Rock in Original Channel
General Condition of Pond	- Good Sediment accumulation at inlet

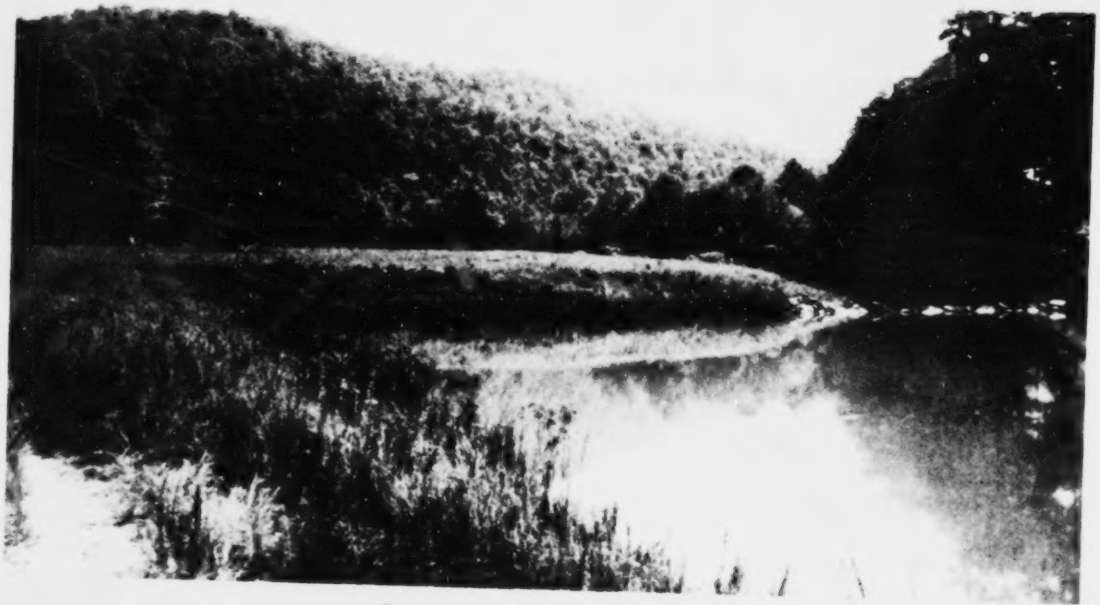


A. View of inlet area.



B. View of body of the pond.

Figure 12. Sediment pond WV-2A



C. View of outlet.

Figure 12. (continued)

The photographs shown in Figures 13A through 13D were taken at sediment pond WV-2B. Figure 13A was taken at the inlet end and shows the use of multiple rock lined entrance channels for erosion preotection and velocity reduction. Figure 13B is a view of the body of the pond looking from the inlet area, Figure 13C is a view looking from the outlet, and Figure 13D is a photograph of the rock lined effluent channel. Having no embankment, and being totally excavated, sediment pond WV-2B is an unusual pond for Appalachian terrain. The material excavated during pond construction was used to reclaim a low lying area adjacent to the pond for farming purposes.

Northeastern West Virginia WV-3--

Sediment pond WV-3 is an experimental pond designed, constructed, and operated by the Environmental Protection Agency near Morgantown, West Virginia. It is an embankment pond with a pipe principal spillway and emergency spillway. Two modifications have been made to the pond in an attempt to improve its removal efficiency. A weir trough has been added to the riser barrel to decrease the effluent velocity, limit short circuiting, and decrease weir loading. A baffle has been added near the pond entrance to decrease influent velocity, aid in settling, and decrease short circuiting. Specific pond physical data are listed in Table 9.

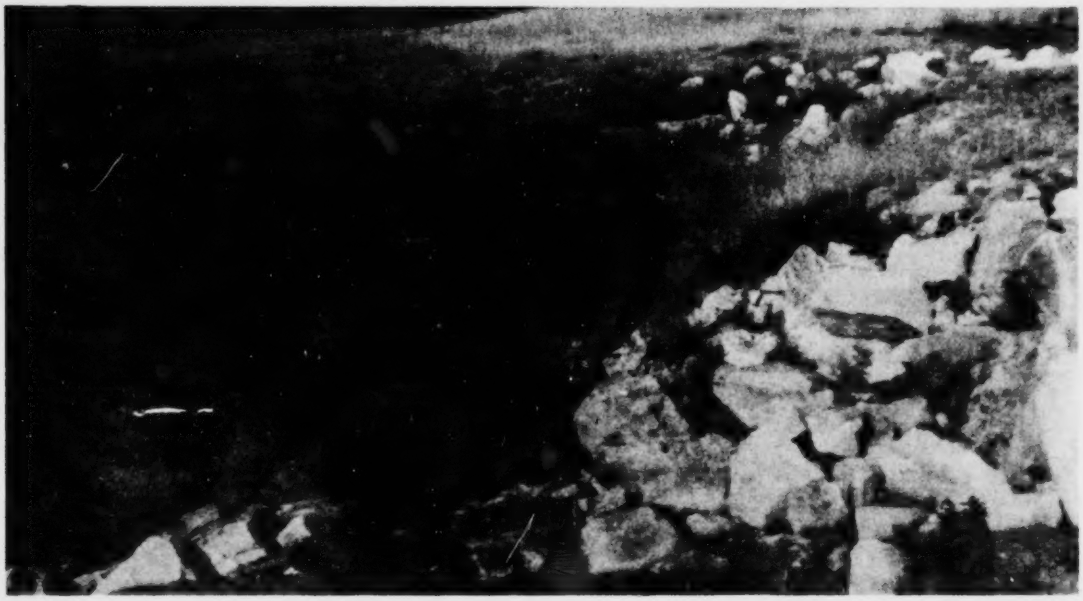
TABLE 8. PHYSICAL CHARACTERISTICS-SEDIMENT POND WV-2B

Physical characteristics	Description
Type	- Excavated Sediment Pond
Location	- On Main Drainage System
Drainage Area	- 562.9 ha (1391 Acres)
Disturbed Area	- 43.7 ha (108 Acres)
Inlet Configuration	- Two Rock Lined Inlet Channels
Body of Pond	- Rectangular 115.8m x 42.7m (380 ft x 140 ft)
Storage Volume	- 7524 m^3 (6.1 Acre-Ft)
Length : Width	- 2.7:1
Outlet Configuration	- Trapezoidal Rock Lined 11.9m (39 ft) Wide at Top 1.5m (5 ft) Deep
General Condition of Pond	- Very Good Erosion control on inlet and outlet Large surface area

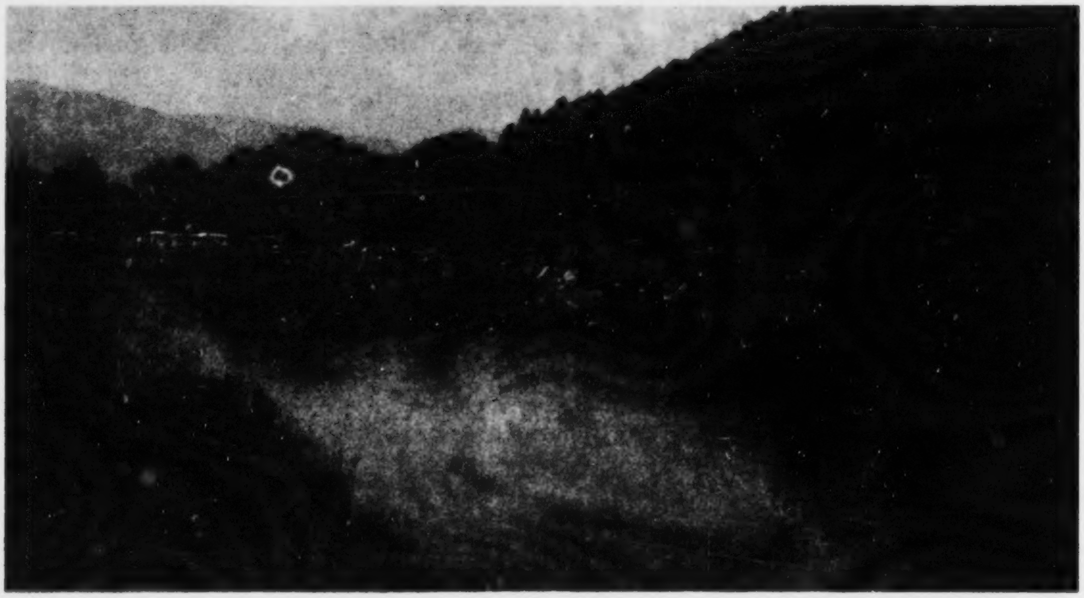
Figure 14A and 14B are photographs of sediment pond WV-3. Figure 14A is a view toward the inlet from the embankment and shows the weir trough and riser barrel discharge device. Figure 14B is a closeup of the weir trough and riser barrel.

Central West Virginia WV-4--

Sediment pond WV-4 is a prime example of a pond designed solely to provide a specific amount of sediment volume without regard to detention time. WV-4 is located downstream from most of this site's mining activity and is designed to provide sediment control for a portion of the mine haul

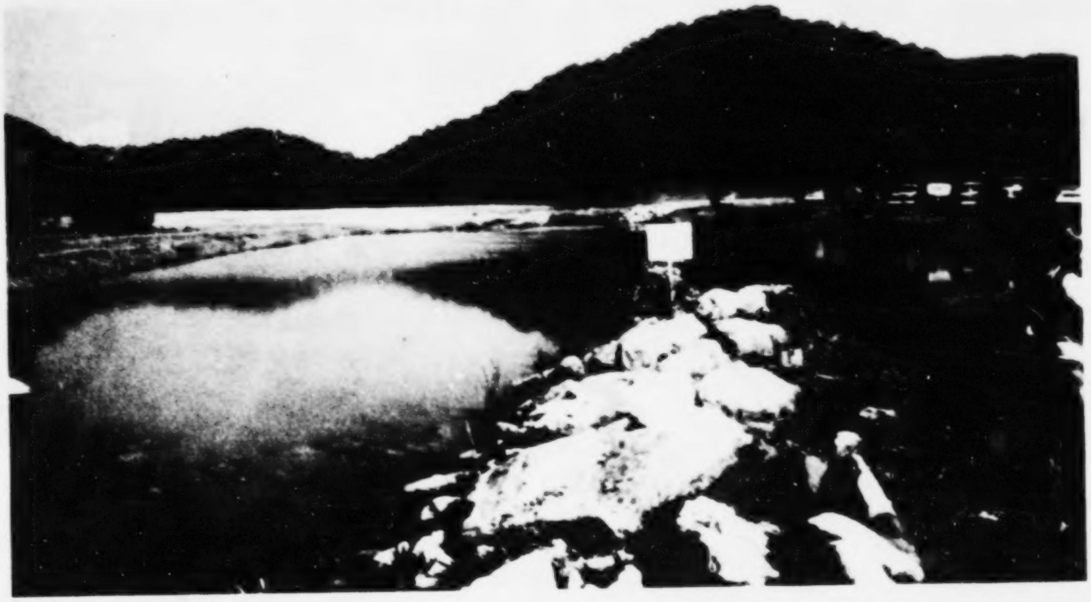


A. View of multiple inlets.

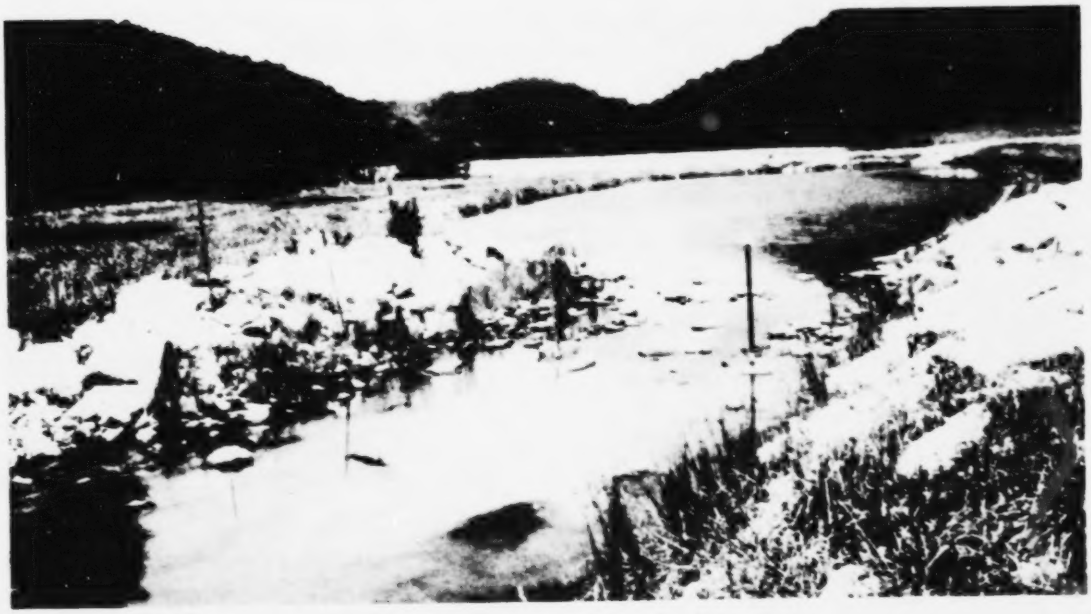


B. View from inlet.

Figure 13. Sediment pond WV-2B.



C. View from effluent channel.

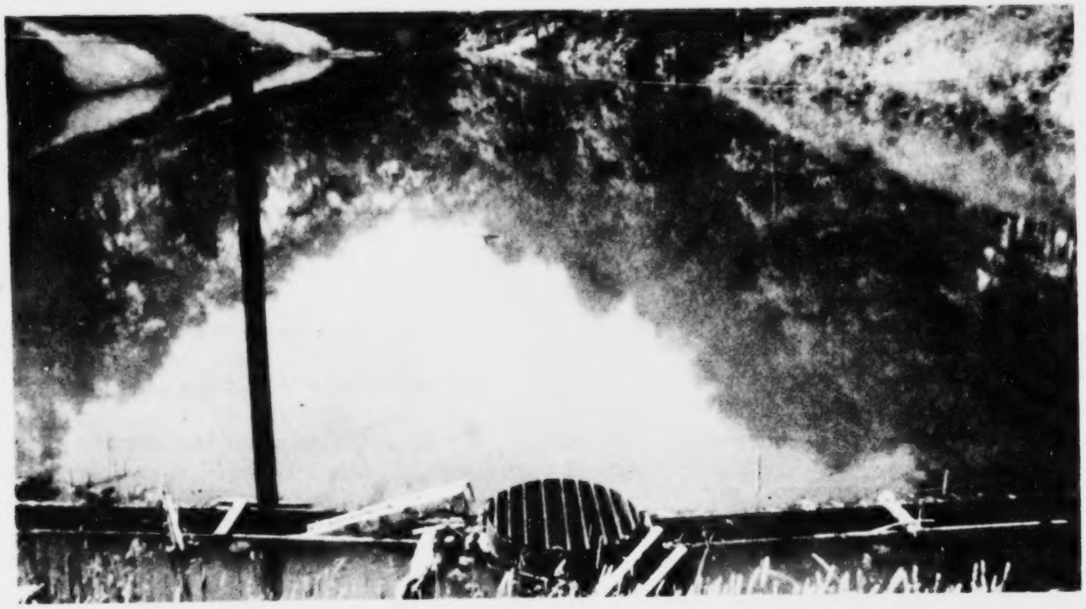


D. Effluent channel.

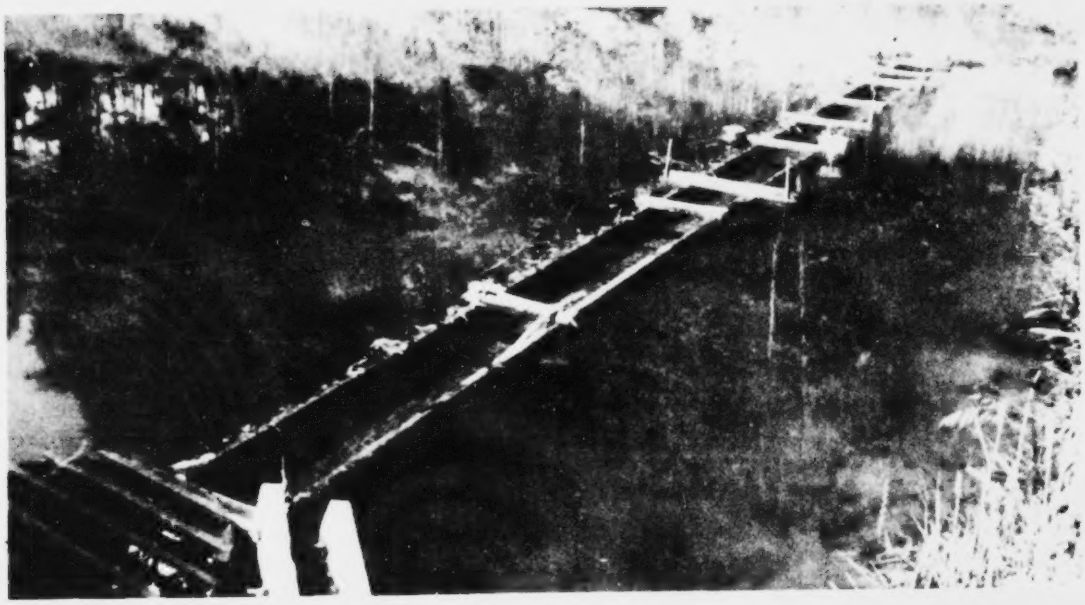
Figure 13. (continued)

TABLE 9. PHYSICAL CHARACTERISTICS-SEDIMENT POND WV-3

Physical characteristics	Description
Type	- Embankment Sediment Pond
Location	- On Main Drainage System
Drainage Area	- 55.1 ha (136 Acres)
Disturbed Area	- 25.9 ha (64 Acres)
Inlet Configuration	- Natural Meandering Stream Channel
Body of Pond	- Rectangular 111.2m x 39.6m (365 ft x 130 ft) Baffle Located 8.5m (28 ft) from Entrance
Storage Volume	- 5674 m^3 (4.6 AF)
Length : Width	- 2.8:1
Outlet Configuration	- Riser 91.4 m (36 in) Smooth Steel Pipe, No Perforations - 0.3m x 0.3m (1 ft x 1 ft) Wooden Broad Crested Weir Trough 30.5m (100 ft) Long Leading to Riser Barrel - Principal Spillway - 61.0 cm (24 in) Smooth Steel Pipe @ 0.66% Slope - 10.2 cm (4 in) Smooth Steel Drainpipe - Trapezoidal Emergency Spillway 20.7m (68 ft) Bottom Width 0.9m (3 ft) Deep
General Condition of Pond	- Pond area between entrance and baffle has accumulated sediment to top of baffle.



A. View from embankment.



B. Effluent weir trough.

Figure 14. Sediment pond WV-3.

TABLE 10. PHYSICAL CHARACTERISTICS-SEDIMENT POND WV-4

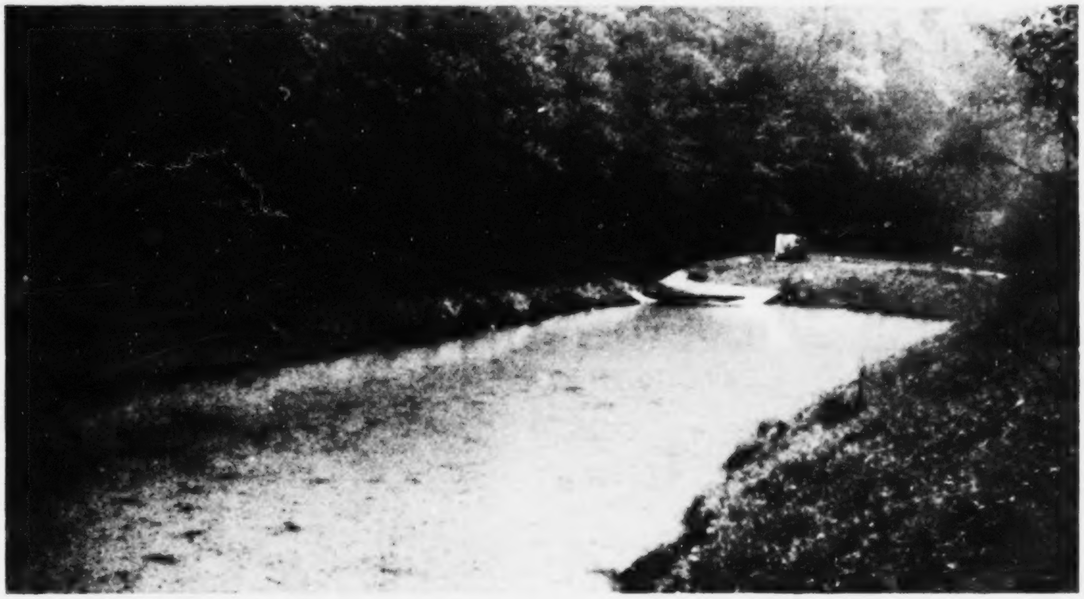
Physical characteristics	Description
Type	- Excavated Sediment Dam
Location	- On Main Drainage System
Drainage Area	- 151 ha (375 Acres)
Disturbed Area	- 5.3 ha (13.2 Acres)
Inlet Configuration	- Natural Stream Channel 1.2m (4 ft) - 3.1m (10 ft) Wide
Body of Pond	- Rectangular 64.0m x 14.6m (210 ft x 48 ft)
Storage Volume	- 2400m^3 (1.9 Ac-ft)
Length : Width	- 4.4:1
Outlet Configuration	- Concrete Spillway 2.4m (8 ft) - 3.6m (12 ft) Wide
General Condition of Pond	- Accumulated sediment should be removed Poor erosion control at inlet

road. It receives drainage, however, from the total area above the pond, thereby severely limiting detention time. The pond is an excavated embankment type rectangular in shape. Specific physical details are listed in Table 10.

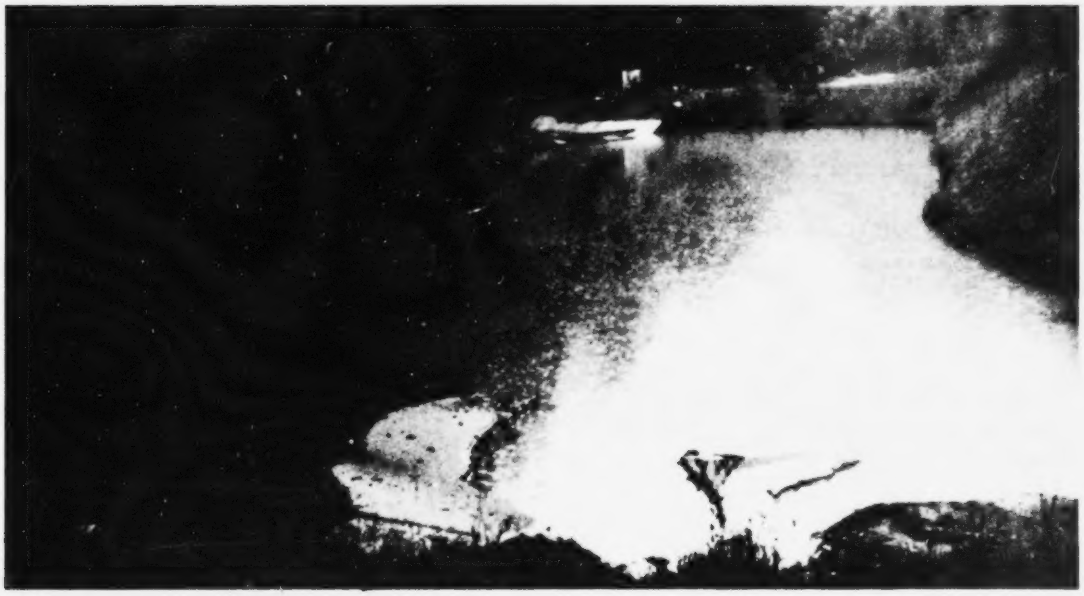
Figures 15A and 15B are photographs of sediment pond WV-4. Figure 15A is a photograph of the body of the pond with the embankment and spillway in the upper right background. Figure 15B is also a photograph of the body of the pond but showing the inlet area in the left foreground.

Southeastern Kentucky KY-1--

Sediment pond KY-1 is located in the southeastern section of Kentucky and is an example of a pond design based upon the requirements of the Office of Surface Mining of the U.S. Department of the Interior in effect at the time of design. The pond has a sediment storage volume equivalent to 0.2 acre-feet per acre of disturbed area and runoff storage equivalent



A. View of embankment and spillway.



B. Inlet area of pond.

Figure 15. Sediment pond WV-4.

to the runoff from a 10-year 24-hour storm. It is an excavated pond with an embankment, having a principal spillway of a pipe with riser barrel in association with an excavated emergency spillway. The pond is situated directly downstream from the tow of a valley fill and treats the runoff from the fill and the mine bench above it. The physical details of the pond are listed in Table 11.

Two photographs of sediment pond KY-1 are displayed in Figures 16A and 16B. Figure 16A is a view of the pond body taken from the embankment showing the inlet area in the background and the riser barrel with anti-vortex device in the foreground. Figure 16B is a view taken from the inlet area showing the embankment, riser barrel, and emergency spillway in the background.

Evaluation of Model Pond Efficiency

The second phase in the evaluation of the model ponds was the determination of their performance under the conditions observed during the sampling period and their theoretical performance during three rare storm events. The theoretical performance criteria was chosen because of the current regulations regarding the effluent limitations from surface mine sedimentation ponds. The effluent limitations are applicable for sediment ponds during storm events up to and including the 10-year, 24-hour storm.

In order to determine sediment pond performance, certain laboratory tests must be performed on the influent and effluent water samples:

1. General chemical parameters
2. Total suspended solids
3. Particle size distribution

With the data from these tests and the physical characteristics of each pond, the efficiency of each model pond was determined.

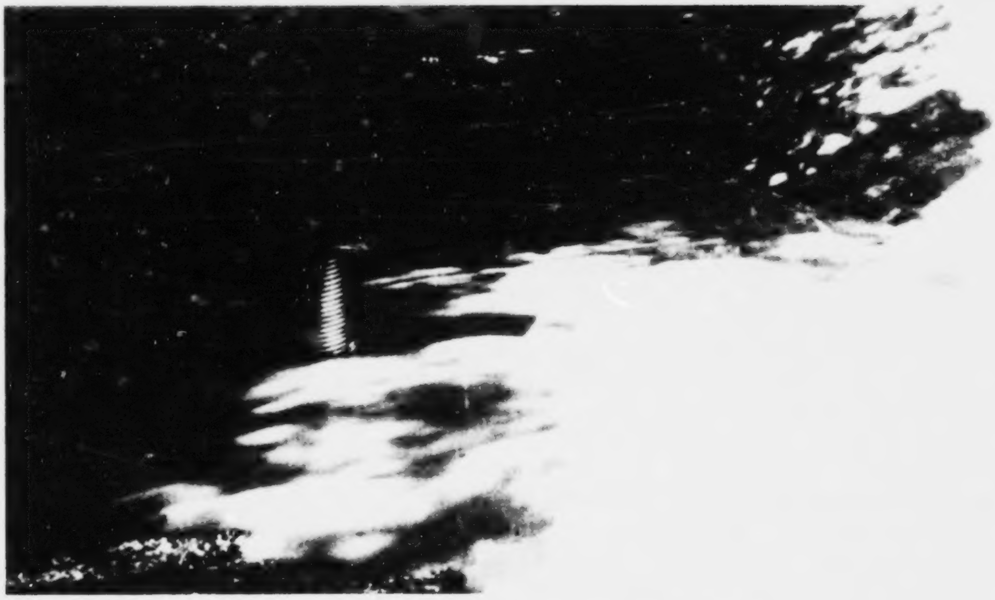
Laboratory Testing Results--

During the period August - November 1978, grab water samples were obtained from the influent and effluent of the six model sediment ponds and were analyzed for the following chemical parameters:

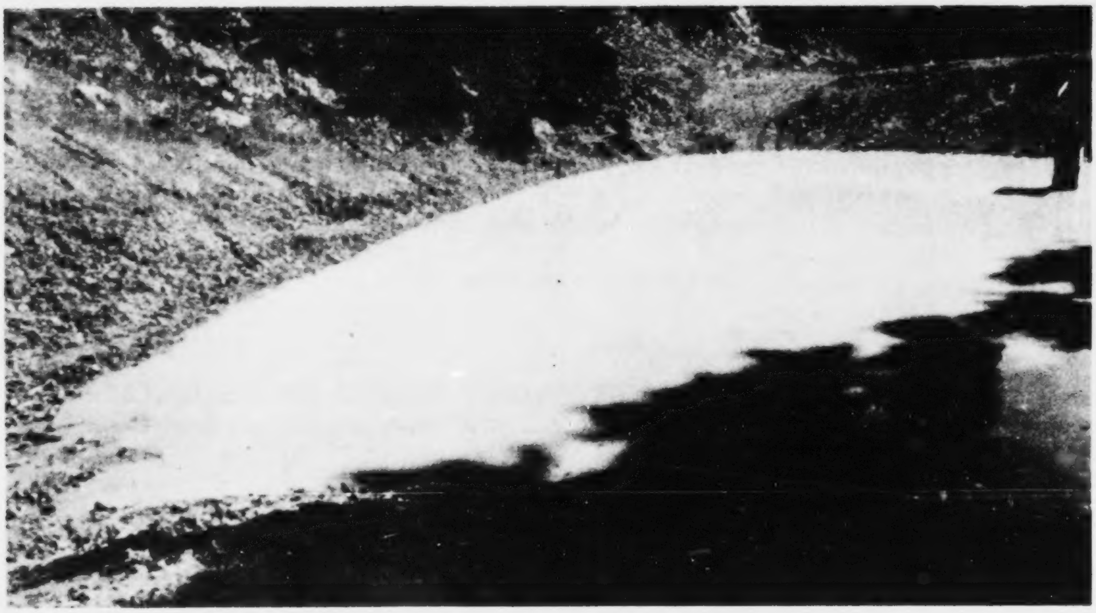
- pH
- Total alkalinity (mg/1 as Ca CO_3)
- Hot acidity (mg/1 as Ca CO_3)
- Turbidity (JTU)
- SO_4 (mg/1)
- Ca (mg/1)

TABLE 11. PHYSICAL CHARACTERISTICS-SEDIMENT POND KY-1

Physical characteristics	Description
Type	- Excavated Embankment Sediment pond
Location	- On Main Drainage System
Drainage Area	- 18.2 ha (45 Acres)
Disturbed Area	- 4.6 ha (15 Acres)
Inlet Configuration	- Natural Stream Channel
Body of Pond	- Pear Shaped 21.3m (70 ft) at Dam × 24.4m (80 ft) Long
Design Storage Volume	- 7067 m^3(5.73 Ac-ft)
Sediment Storage	- 3823 m^3(3.1 Ac-ft)
Runoff Storage	- 1233 m^3(2.63 Ac-ft)
Length : Width	- 2.1:1
Outlet Configuration	- Principal Spillway 38.1 cm (15 in) Corrugated Metal Pipe with 53.3 cm (21 in) Corrugated Metal Pipe Riser - Trapezoidal Emergency Spillway 6.1 m (20 ft) Bottom Width 0.76 m (2.5 ft) Depth
General Condition of Pond	- Recently Constructed No energy dissipation on inlet No erosion protection on emergency spillway



A. View of body of the pond.



B. View of embankment, riser barrel and emergency spillway.

Figure 16. Sediment pond KY-1.

- Mg (mg/1)
- Total solids (mg/1)
- Total suspended solids (mg/1)
- Settleable solids (mg/1)
- Total Fe (mg/1)
- Mn (mg/1)

The results of the chemical analyses are shown in Table 13.

Additional testing performed on the water samples included a particle size distribution analysis on the influent which are depicted in Figures 17 thru 23. The particle size distribution analysis was performed by first filtering the sample through a 45 micron filter to remove the larger particles. After filtering, the filtrate was processed with a Coulter Counter to measure the specific particle sizes.

Efficiency of Removal During Sampling Period--

As previously mentioned, the water samples were taken during or directly after storm events in the drainage area of each pond. Table 12 shows the amount of rainfall associated with the precipitation events occurring or preceding the sample period, the influent and effluent suspended solids, and the percent removal of suspended solids by each sediment pond.

One must be cautioned when trying to draw conclusions from the percent removals of the pond tabulated below. Due to the nature of the sampling programs, grab samples vs continuous monitoring, a definite percent removal cannot be determined with confidence; rather, only a preliminary indication of removal efficiency can be obtained from this data.

It should be noted that rainfall data was derived, not from onsite measurements, but from the nearest meteorological station. Thus rainfall data shown could be quite inaccurate, depending on local weather conditions, storm movement, and the distance from the measuring point to the actual mine site, and is presented here only as a general indication of the type of rainfall event.

TABLE 12. MODEL SEDIMENT POND EFFICIENCY

Pond	Date	Rainfall		Suspended Solids (mg/l)		Removal %
		(cm)	(in)	Influent	Effluent	
PA-1	8/29/78	3.25	1.28	437	22	95
WV-1	8/15/78	0.43	0.17	2300	21	99
WV-2A	10/13/78	1.27	0.5	148	6	96
WV-2B	10/13/78	1.27	0.5	8, (31)	47	--
WV-3	11/27/78	1.17	0.44	4510	45	99
WV-4	10/26/78	2.41	0.95	2454	39	98
KY-1	11/16/78	1.65	0.65	606	183	70

TABLE 13. WATER QUALITY OF MODEL SEDIMENT PONDS

	Model sediment ponds														
	PA-1 (Inf)	PA-1 (Eff)	WV-1 (Inf)	WV-1 (Eff)	WV-2A (Inf)	WV-2A (Eff)	WV-2BL (Inf)	WV-2BR (Inf)	WV-2B (Eff)	WV-3 (Inf)	WV-3 (Eff)	WV-4 (Inf)	WV-4 (Eff)	KY-1 (Inf)	KY-1 (Eff)
pH	5.8	5.2	8.1	8.3	5.6	6.1	6.0	6.3	5.7	7.4	7.5	6.4	6.7	7.0	7.0
Total alkalinity (mg/l as Ca CO_3)	18	14	176	178	14	20	16	124	10	138	152	36	30	82	52
Hot acidity (mg/l as Ca CO_3)	+12	+4	-168	-158	-4	-10	-6	-130	-2	-116	-136	+30	-12	-58	-32
Turbidity (JTU)	880	34	440	22	64	4.9	12	26	20	200	42	440	38	680	92
SO_4 (mg/l)	215	195	290	260	39	41	27	39	7.8	180	150	110	77	79	72
Ca (mg/l)	45	47	93.2	90.3	11.4	17.5	9.7	10.8	3.5	90	71	27	27	35	25
Mg (mg/l)	26	19.4	58	57	6.3	5.5	4.7	5.4	1.6	31.6	23.7	18.0	16.5	21.7	15.2
Total solids (mg/l)	1,413	433	3,447	817	253	106	93	128	108	4,975	423	3,089	330	996	376
Total suspended solids (mg/l)	437	22	2,306	21	148	6	8	31	47	4,510	45	2,454	39	606	183
Settleable solids (ml/l)	5.0	0.1	24	0.3	2.5	2.1	0.1	0.3	0.8	40	<0.1	8.0	0.2	3.5	0.2
Total Fe (mg/l)	8.5	0.17	15.6	0.26	5.00	0.45	1.70	1.76	1.13	34.3	0.46	13.5	0.69	4.04	1.39
Mn (mg/l)	2.10	3.3	0.97	0.18	0.56	0.26	0.33	0.21	0.11	2.25	0.53	4.2	2.9	2.49	0.31

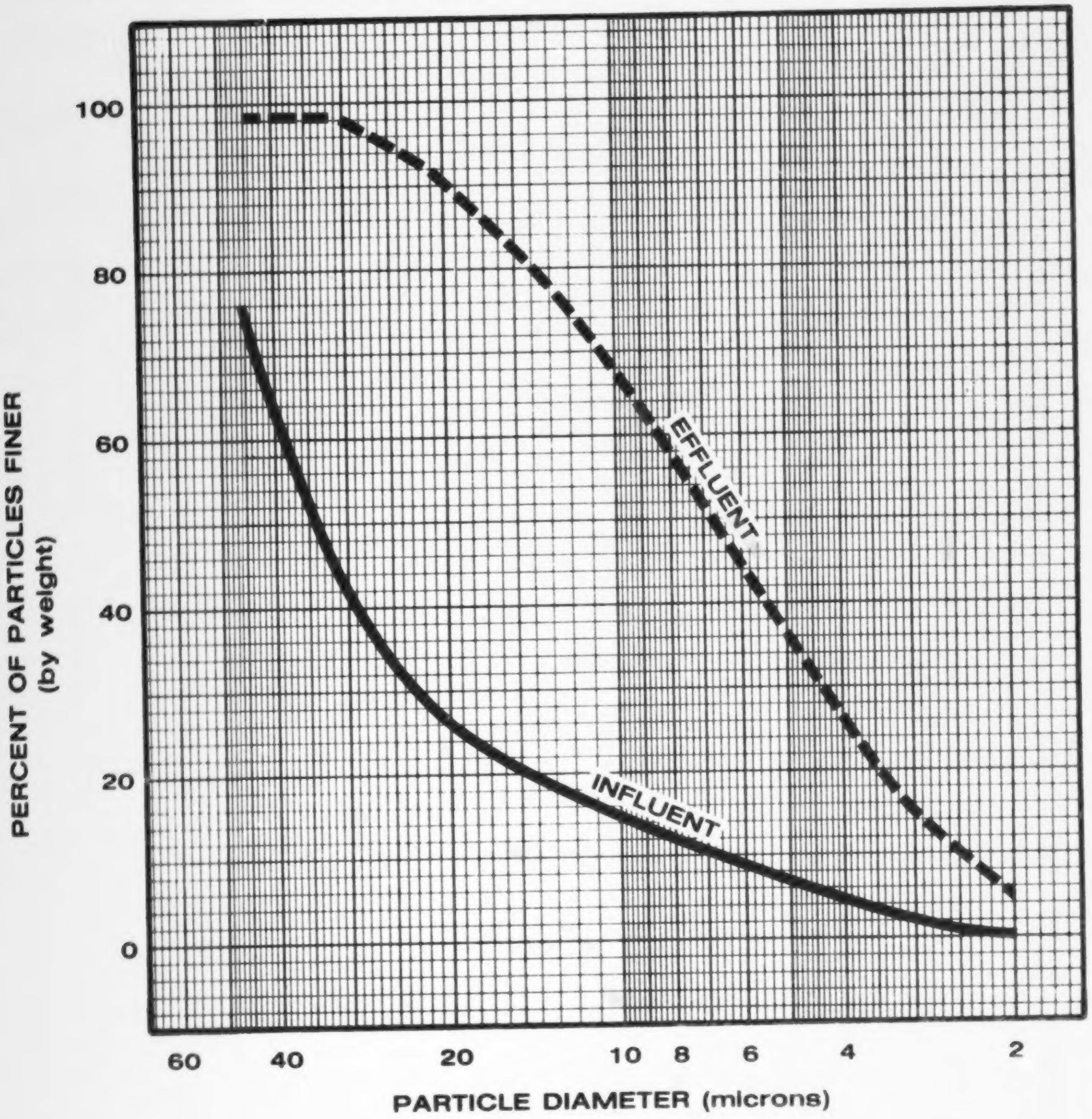


Figure 17. Particle size distribution PA-1.

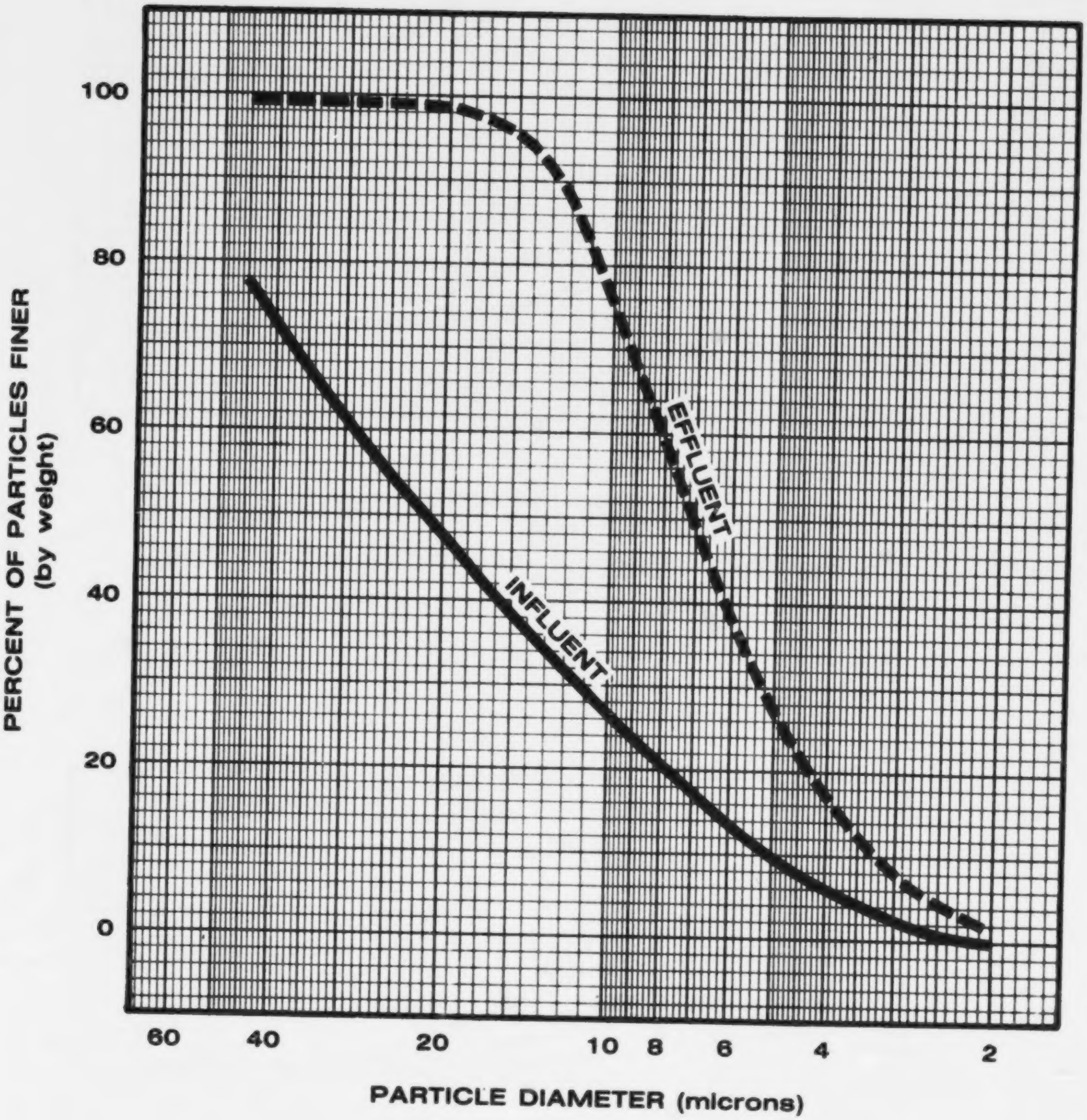


Figure 18. Particle size distribution WV-1.

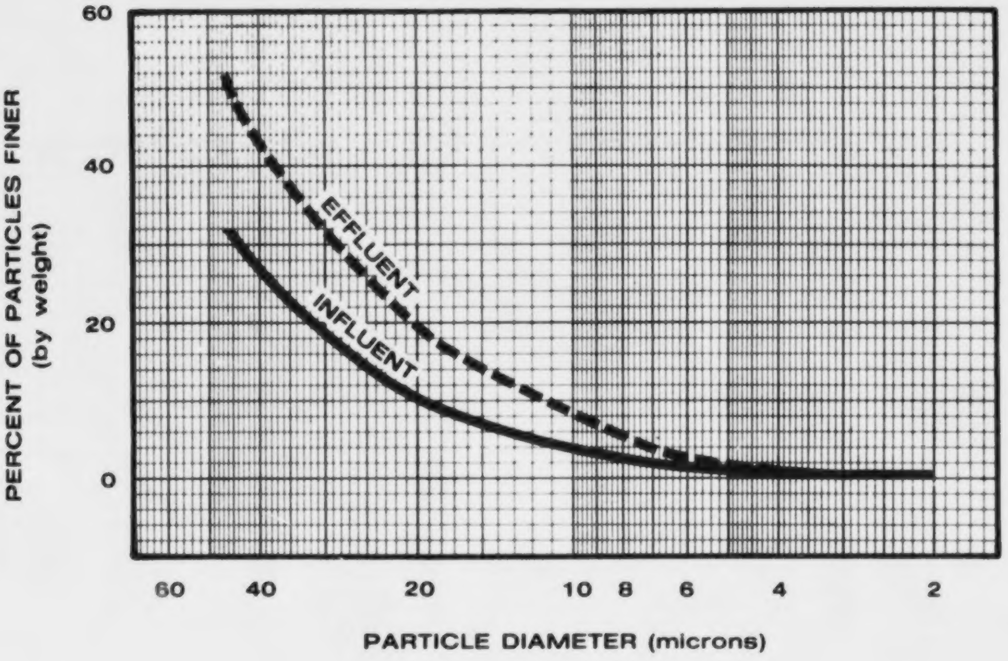


Figure 19. Particle size distribution WV-2A.

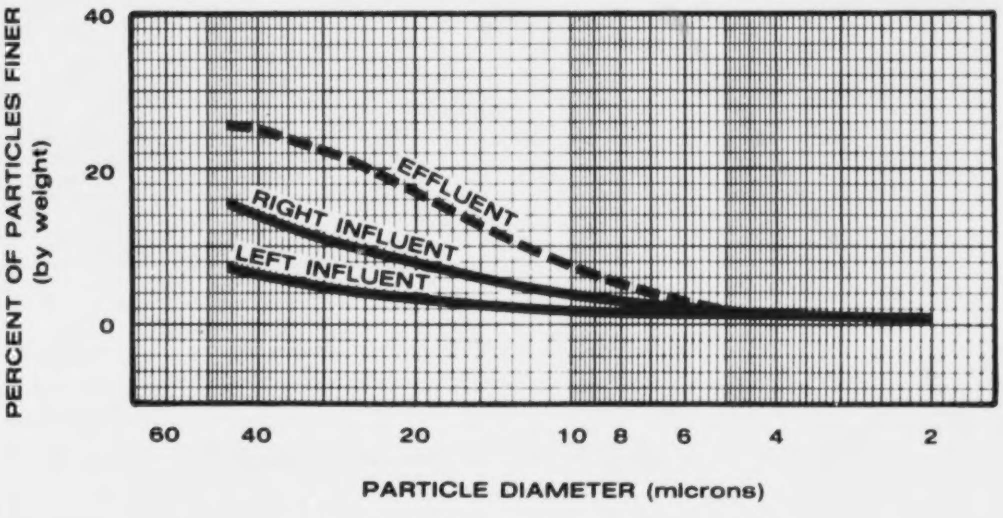


Figure 20. Particle size distribution WV-2B.

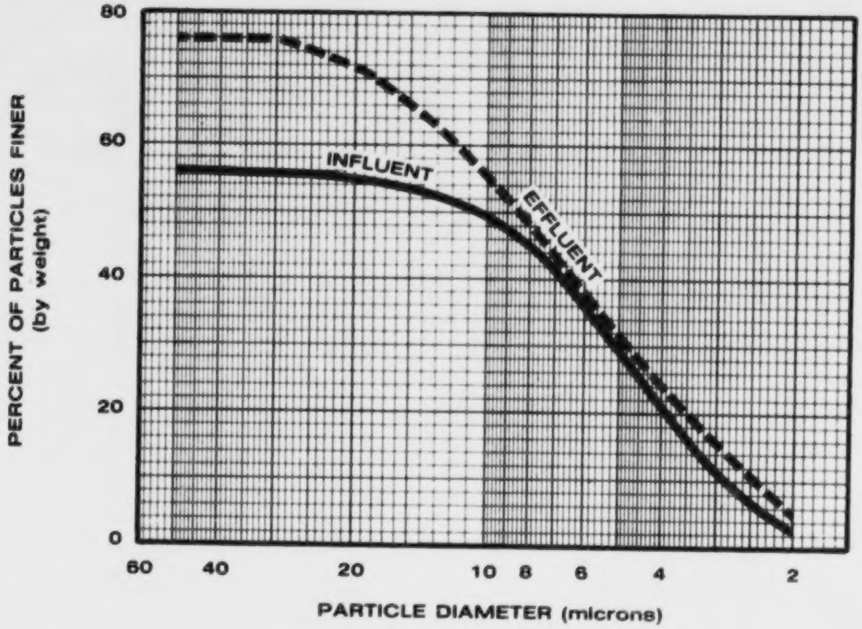


Figure 21. Particle size distribution WV-3.

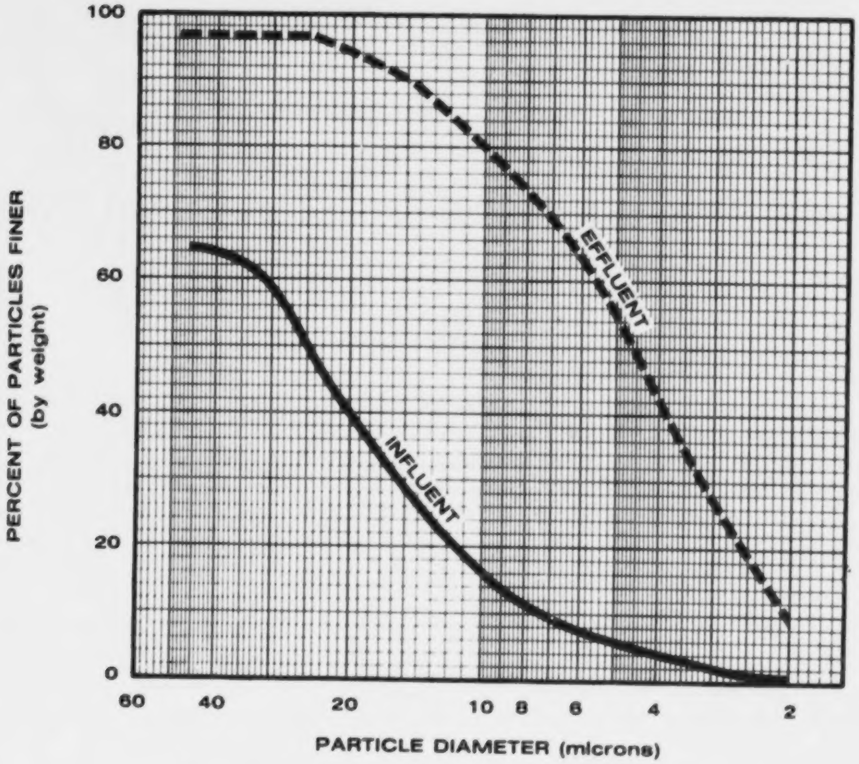


Figure 22. Particle size distribution WV-4.

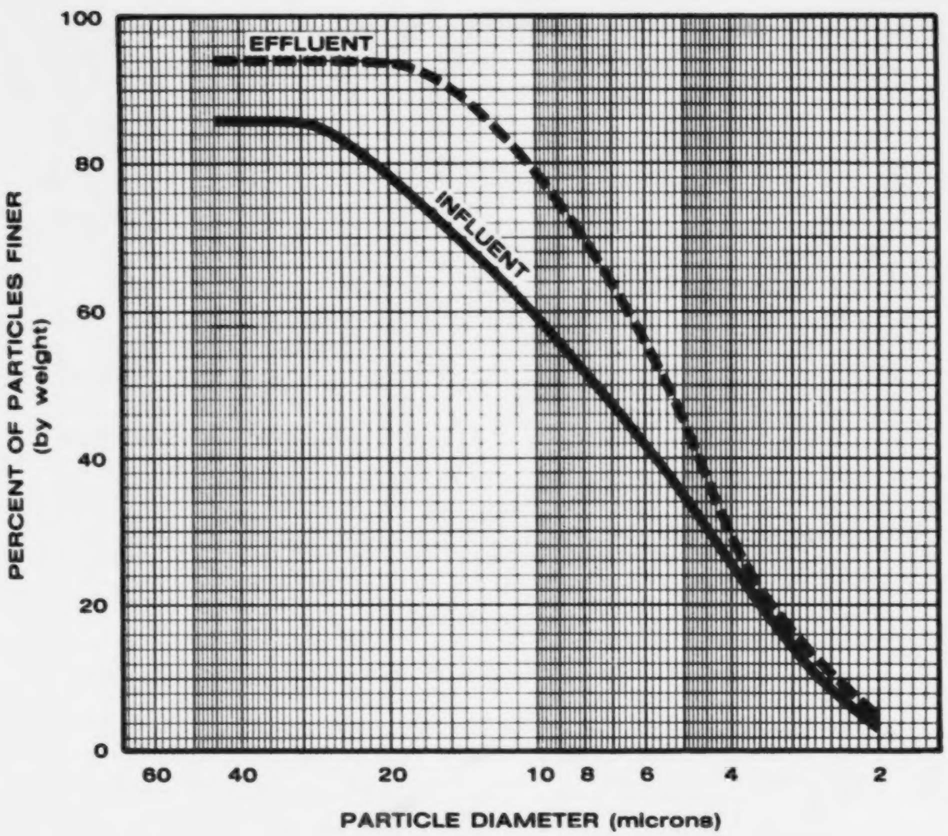


Figure 23. Particle size distribution KY-1.

Theoretical Efficiency During a Rare Storm Event--

During a recent study, the six sediment ponds referred to in this report were evaluated to determine size requirements to meet current OSM specifications and to determine their effectiveness in sediment removal during the occurrence of a variety of rare storm events. Through the use of computer simulation techniques, the six sediment ponds, redesigned to OSM specifications, were studied to determine their performance during the experience of three discrete precipitation events, the 2-year, 5-year, and 10-year 24-hour storms.

First, sediment ponds meeting current OSM requirements were designed to provide sediment storage of 0.1 AF/acre of disturbed area and a detention storage equivalent to the runoff from a 10-year 24-hour storm. The total storage of each sediment pond is detailed in Table 14.

TABLE 14. SEDIMENT POND STORAGE CAPACITY

	Current storage volume		OSM design volume		Increase in size
	(m^3)	(AF)	(m^3)	(AF)	%
PA-1	764	0.62	10,120	8.2	1220
WV-1	3330	2.7	34,500	28.0	937
WV-2A	5550	4.5	35,200	28.5	533
WV-3	5674	4.6	23,900	19.4	322
WV-4	2400	1.9	24,700	20.0	952
KY-1	7067	5.7	6,400	5.2	-8.8

In order to evaluate the performance of these sediment ponds, a three-step approach was employed. First, the gross erosion in tons from the watershed tributary to the ponds was computed for the 2-year, 5-year, and 10-year 24-hour storm events. Second, the inflow hydrograph for each sediment pond was computed for the three storm events. Finally, the performance of each sediment pond was evaluated using a computer program developed by the University of Kentucky Department of Agricultural Engineering. The results of this computer evaluation are detailed in Table 15. The results of the 2-year precipitation event are not included in this summary because the computer model simulated 100% trap efficiency for the total runoff. Because the computer model simulates flow through the basin as plug flow, the model assumes that the runoff from the 2-year storm event displaces the permanent pool of "clear" water. In an actual field situation, the pre-storm contents of the permanent pool which will be discharged prior to storm discharge will contain an unknown amount of colloidal material contributing to suspended solids in the effluent. Review of the data presented in Table shows that none of the enlarged basins met the suspended solids effluent limitations for the 5- and 10-year storms. For example, sediment pond PA-1, increased in size by 1220%, still produced a peak effluent concentration thirty-three times larger than the maximum allowable. It is obvious that the existing sediment ponds would perform poorly during a rare storm event.

REVIEW OF PHYSICAL MODIFICATION ALTERNATIVES

During the course of Phase I of this study, it has become apparent that physical modification to sediment ponds may be made in any one of the three distinct parts of the pond:

1. Inlet portion
2. Body of the pond
3. Outlet portion

TABLE 15. SUMMARY OF SIMULATED SEDIMENT POND PERFORMANCE[11]

Pond	Precipitation event frequency 24 hr. duration	Detention time (hours)	Suspended solids (mg/l)		Basin trap efficiency (%)
			peak inf.	peak eff.	
PA-1	5-year	20.8	52,300	1730	99.0
	10-year	25.0	54,300	2310	97.5
WV-1	5-year	25.7	21,000	1240	95.9
	10-year	26.1	22,630	1280	94.3
WV-2A	5-year	13.9	5,700	430	94.0
	10-year	24.7	6,180	460	93.8
WV-3	5-year	26.3	41,300	1590	98.0
	10-year	26.3	41,300	2300	95.8
WV-4	5-year	15.4	15,100	1240	93.5
	10-year	25.7	17,100	1340	94.4
KY-1	5-year	16.3	10,700	590	95.8
	10-year	26.2	10,400	646	94.9

The purpose of modifying the sediment pond's physical characteristics in these three areas is twofold; an attempt to simulate as close as possible the characteristics of an optimum theoretical sedimentation pond in the real world and an attempt to lessen the loading of sediment entering the basin. Simulation of near optimum performance can be accomplished by the reduction of short circuiting by use of a flared modified inlet, by a large surface area in the body of the pond or by the use of multiple outlets. Reduction of sediment loading to the pond may be accomplished by erosion control measures such as silt fences or log and pole structures. No matter what modification is proposed, one of two themes will be present; simulation of optimum conditions or reduction of sediment loading.

Inlet Modifications

Modifications to the inlet of a sedimentation pond can be designed with any or all of three primary options in mind: 1) dissipation of energy in the influent to the basin, 2) distribution of the influent over the width of the pond; and 3) filtration of the influent.

Energy Dissipaters--

An energy dissipation device decreases the inlet water velocity, thereby causing a fraction of the incoming suspended solids to settle out immediately. A partial list of energy dissipation devices will include dumped rock at the pond inlet, log or pole structures, and stone check dams.

The simplest energy dissipater consists of dumped rock placed at the end of the inlet channel as it enters the body of the pond. This technique effectively reduces the water velocity at the inlet causing some sediment to settle out and a delta of sediment is created beyond the dissipater as shown in Figure 24. Table 16 indicates the maximum size particle which will be scoured from the bottom at the velocities shown. Reference 13 has a useful section on design of outlet protection using riprap which would also be applicable here and should be consulted when using a riprap energy dissipater.

Another technique which provides a combination of energy dissipation and staged settling is a log or pole structure. This structure is a barrier constructed of logs or poles cut during clearing of the area. The logs and poles are placed across a natural or constructed drainway in an upright position as shown in Figure 25. The purpose of this structure is to retard stream flow and catch the larger particles of sediment. One problem encountered with the use of these structures is the removal of the trapped sediment. Care must be taken that another structure is in place downstream in order to trap sediment released during the removal of the upstream structure.

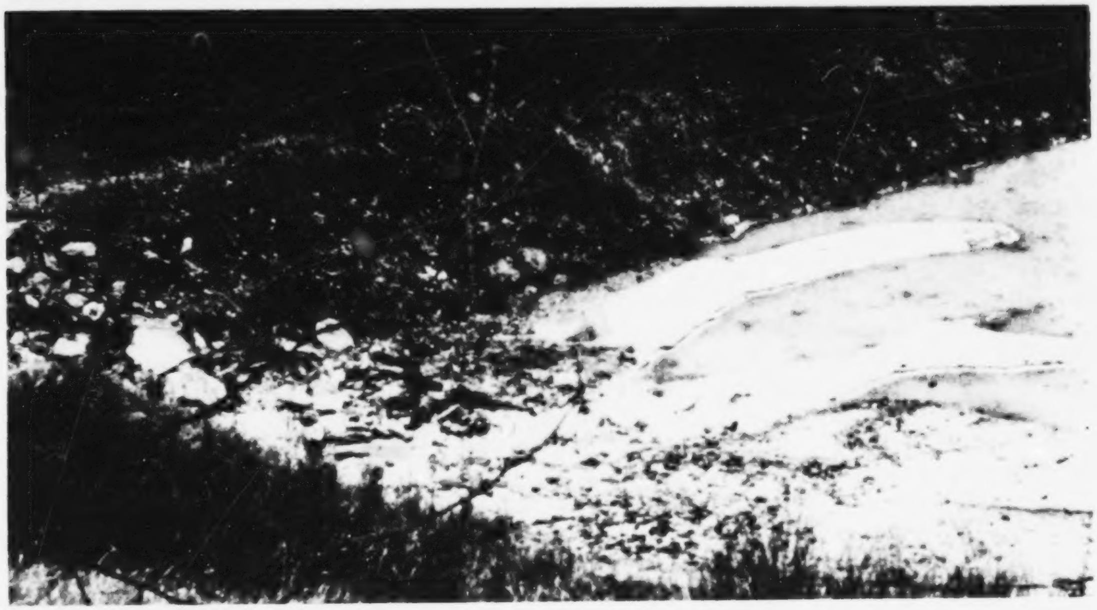


Figure 24. Influent energy dissipation by dumped rock.

TABLE 16. SCOUR VELOCITY VS PARTICLE SIZE

SPECIFIC GRAVITY = 2.65
B = .04
F = .02

Velocity (cm/sec)	Particle size (millimeters)
15.24	0.009
30.48	0.036
45.72	0.080
60.96	0.143
91.44	0.323
121.92	0.574

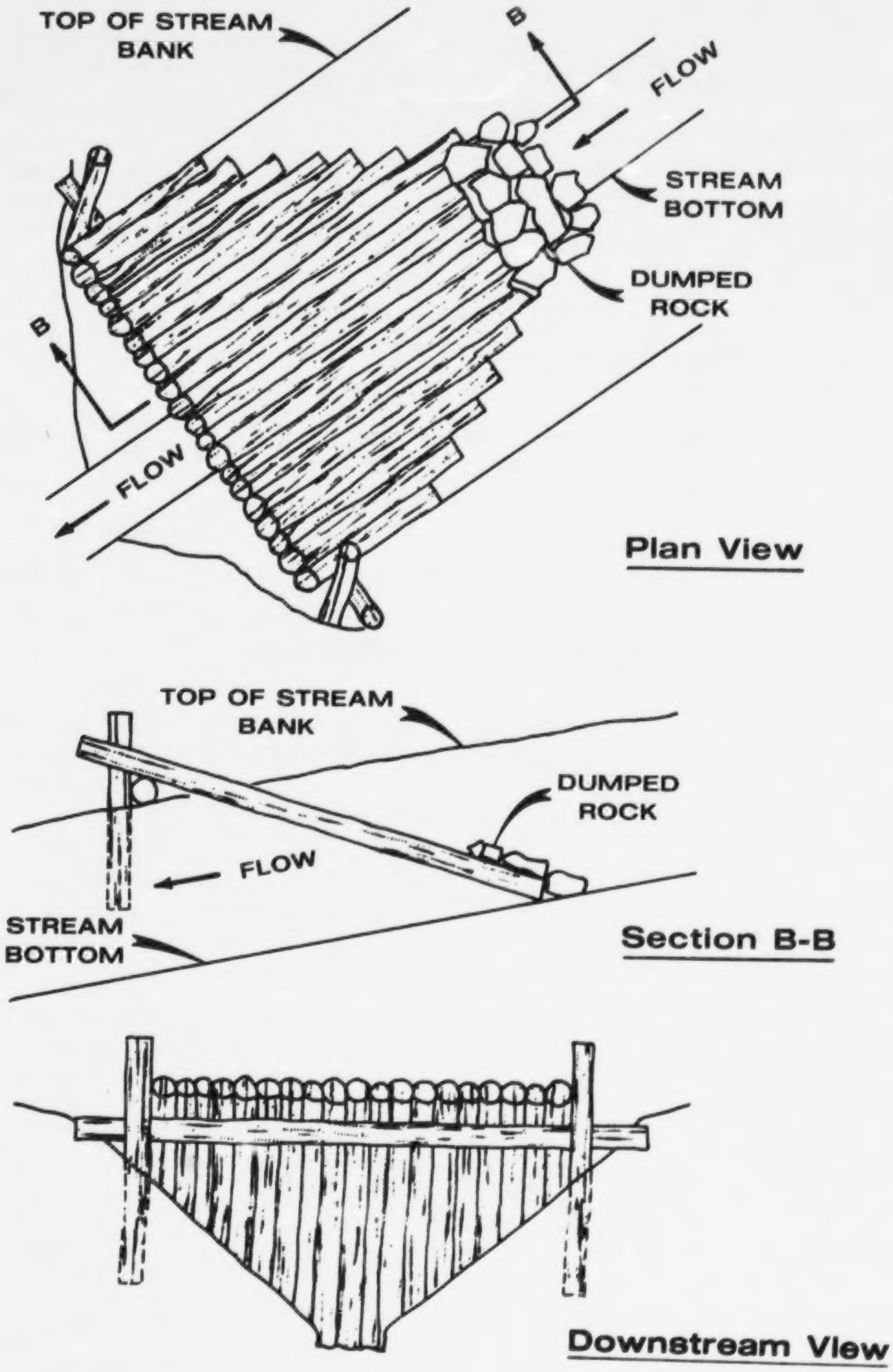

TOP OF STREAM BANK
B
FLOW
STREAM BOTTOM
DUMPED ROCK
B
FLOW
Plan View
TOP OF STREAM BANK
DUMPED ROCK
FLOW
STREAM BOTTOM
Section B-B
Downstream View

Figure 25. Log and pole silt structure.[12]

A third type of energy dissipation structure may also be used on the upstream section of the inlet channel. This structure is a stone check dam and is a barrier of large stone built across a drainway. The purpose of this dam is to reduce stream velocity and form a small sediment catch basin. Stone check dams are often used in natural drainways directly adjacent to the disturbed area in order to trap the larger sediment particles before they reach the sediment pond. There are specific requirements for stone check dams in the states of West Virginia and Kentucky as follows:

1. 25% of the rock must be 46 cm (18 in) or larger with remaining to be well-graded to fill voids.
2. The dam must be keyed into the sides and bottom of channel a minimum depth and width of 0.91 meters (3 ft)
3. The upstream and downstream slope of the dam may be no steeper than 3:1.
4. A weir must be constructed the average width of the channel with a minimum depth of one foot at the center of the dam.
5. Maximum height permitted is four feet from original channel at centerline of dam to crest of weir.
6. Minimum top width of the weir is five feet.[13]

In Kentucky, a check dam may be constructed of logs six inches or greater in diameter, placed horizontally in the stream channel. Log and stone check dams are shown in Figures 26 and 27 respectively.

Flow Distribution--

A second major means of modification again deals with inlet structures and involves use of some method to discharge the influent over the total width of the sediment pond rather than at a single influent point. This can be accomplished with three techniques, used either separately or in tandem. The three possible modifications include the use of an apron inlet, strategic placement of a baffle at the inlet, or multiple rather than single inlets.

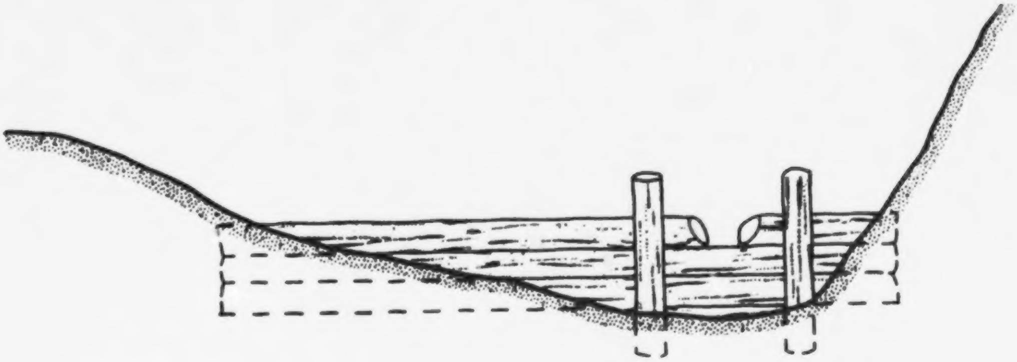


Figure 26. Log check dam.[14]

First, an apron can be built, as shown in Figure 28, at the end of the inlet channel, where it enters the pond, to distribute the flow evenly over the width of the pond. By doing this, short-circuiting through the pond can be lessened. A second method of flow distribution involves use of a baffle within the body of the pond located approximately one-third the distance from the inlet to the outlet to allow for velocity reduction. The baffle, if constructed along the entire width of the pond as shown in Figure 29A, should be an overflow type baffle. In addition to distributing the flow over the total width of the pond, an inlet overflow baffle gives the added benefit of staged settling, since influent velocity reduction occurs rapidly causing the heavier particles to settle out almost immediately. Several types of inlet "directional" baffles, which do not extend the complete width of the pond, may also be used to direct the inflow to the sides of the pond. Figure 29B shows the location and direction of flow; with the inlet directional baffle mounted perpendicular to the influent flow direction, and Figure 29C shows the inlet directional baffle mounted at a 45° angle to the perpendicular of the flow direction. A typical baffle constructed of exterior grade plywood is shown in Figure 30 and may be used as an overflow baffle or as a directional baffle.

Another influent modification for achieving increased influent flow distribution would be the use of multiple inlets. If the sediment

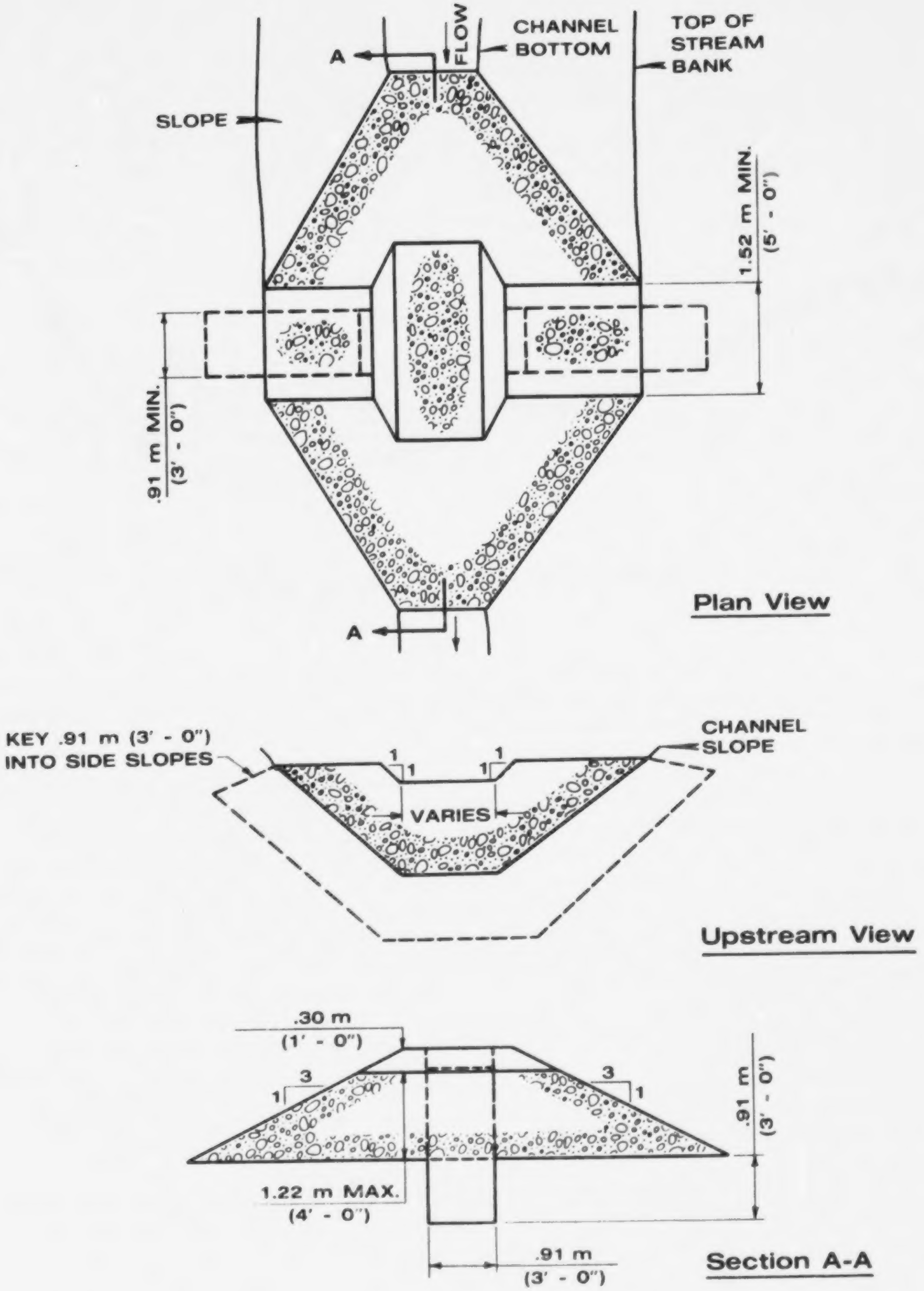

FLOW
CHANNEL BOTTOM
TOP OF STREAM BANK
A
SLOPE
1.52 m MIN. (5' - 0")
.91 m MIN. (3' - 0")
A
Plan View
KEY .91 m (3' - 0") INTO SIDE SLOPES
CHANNEL SLOPE
1
1
1
1
VARIES
Upstream View
.30 m (1' - 0")
3
1
3
1
.91 m (3' - 0")
1.22 m MAX. (4' - 0")
.91 m (3' - 0")
Section A-A

Figure 27. Stone check dam.[15]

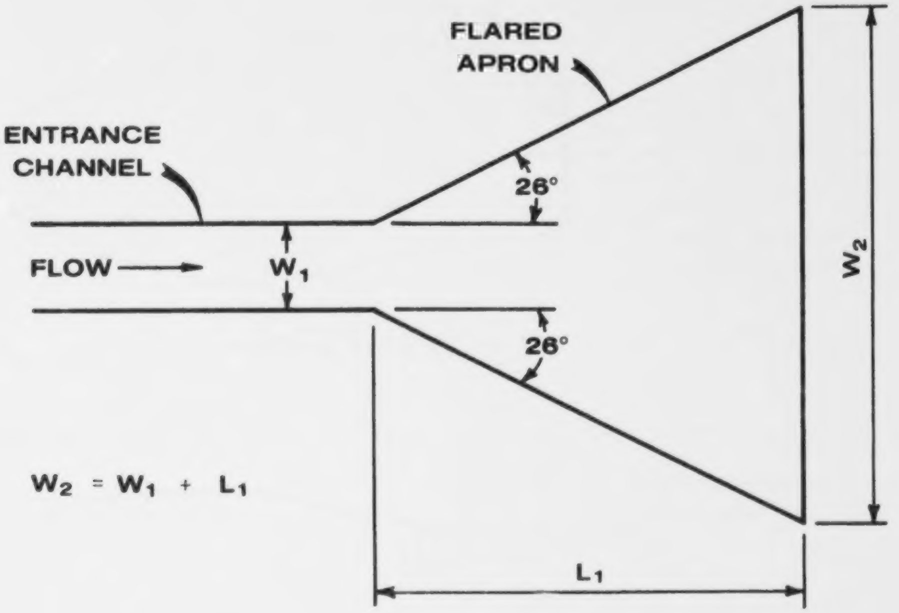
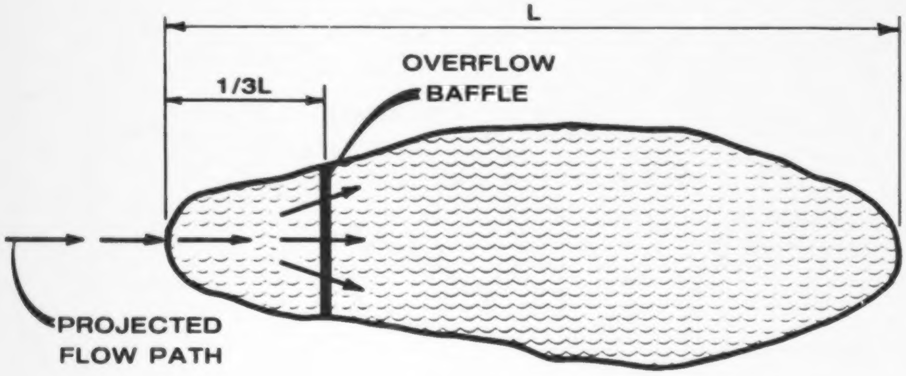
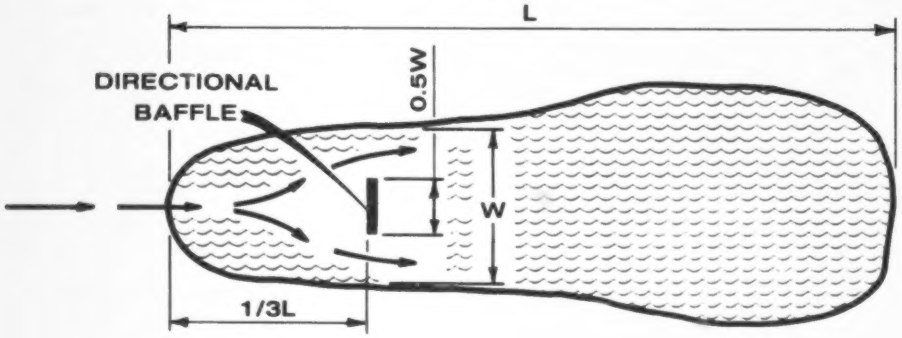


Figure 28. Flared apron entrance channel.[16]

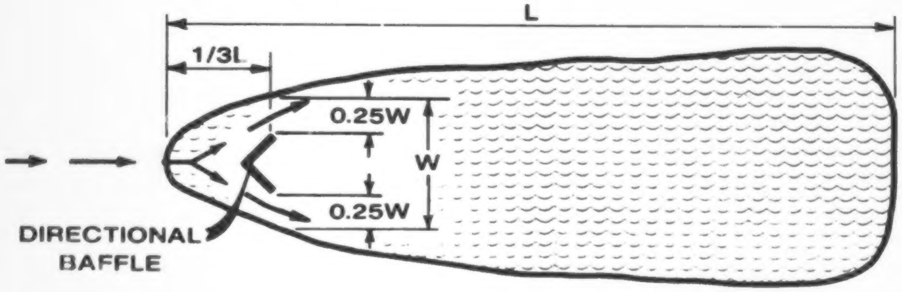
pond to be constructed is of the type located off the main or natural drainage system (away from the stream channel), then multiple inlet flow distribution would be rather simple to add to the design. Construction of multiple inlets in a relatively flat area would not be difficult because there would be no limitations of excavation capability due to topographic constraints. For example, rather than introducing the flow to a rectangular pond at a single point, a branching of the influent channel is possible. If branching is used, care must be taken to provide adequate channel erosion control in order to direct the flow where desired. Figure 31 indicates the branching of flow into a rectangular basin. In this example, two primary branches are shown which will handle normal flow to the basin. The control channel is indicated as secondary and will be used only during high flow conditions. An inlet control device, such as a V - notch weir should be used on the secondary channel to prevent a straight through flow during low flow or a by-passing of the primary branches.


L
1/3L
OVERFLOW
BAFFLE
PROJECTED
FLOW PATH

A. Inlet overflow baffle.


L
DIRECTIONAL
BAFFLE
0.5W
W
1/3L

B. Inlet directional baffle.
(perpendicular)


L
1/3L
0.25W
W
0.25W
DIRECTIONAL
BAFFLE

C. Inlet directional baffle.
(45° angle)

Figure 29. Sediment pond inlet baffles.

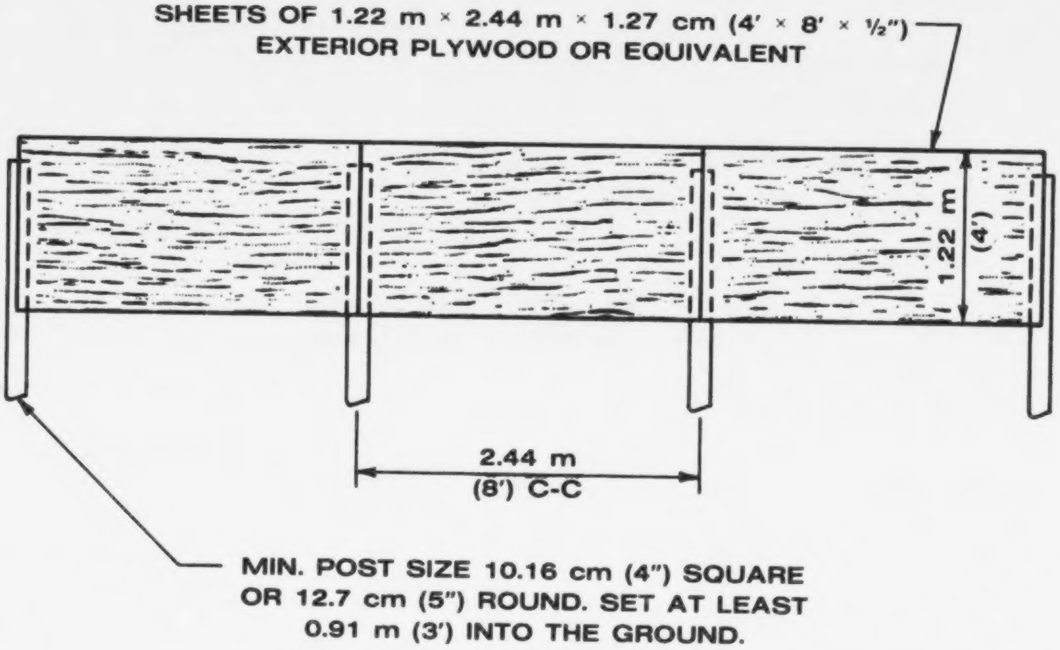
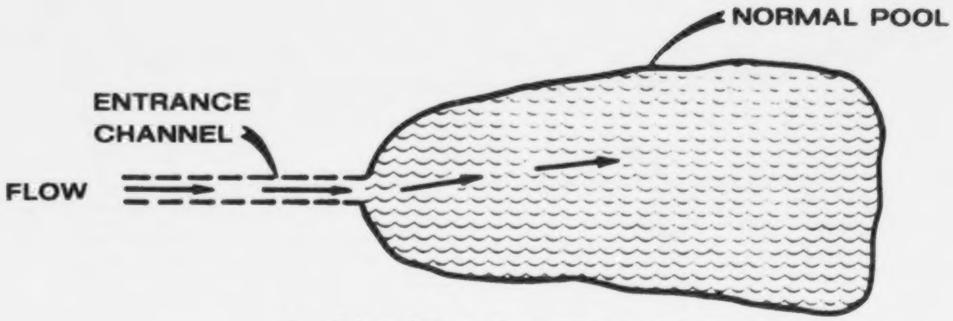

SHEETS OF 1.22 m × 2.44 m × 1.27 cm (4' × 8' × ½")
EXTERIOR PLYWOOD OR EQUIVALENT
1.22 m
(4')
2.44 m
(8') C-C
MIN. POST SIZE 10.16 cm (4") SQUARE
OR 12.7 cm (5") ROUND. SET AT LEAST
0.91 m (3') INTO THE GROUND.

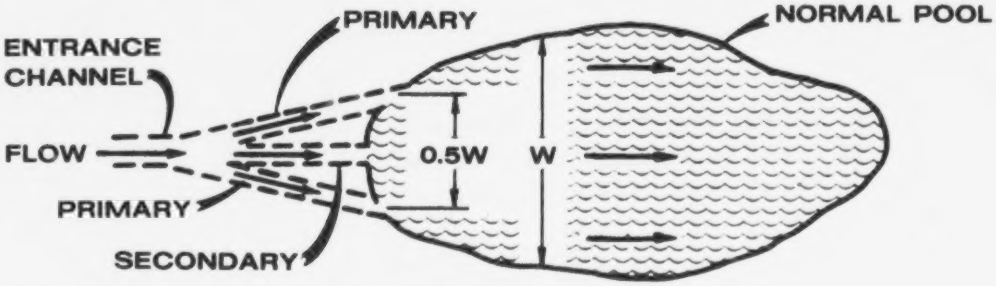
Figure 30. Baffle detail.[17]

Filtration of Influent--

A final modification to the inlet area of a pond introduces the filtration of the influent through a silt fence or straw bale barrier prior to entering the pond. The applicability of this technique is limited to very small drainage areas (.20 ha or less) leading into a sediment pond located off the main drainage system. Figure 32 shows a detail of the placement of a straw bale barrier and Figure 33 depicts the placement of a silt fence both of which should be located on the immediate perimeter of the disturbed area.


NORMAL POOL
ENTRANCE CHANNEL
FLOW

A. Single point entrance
(promotes short circuiting)


PRIMARY
NORMAL POOL
ENTRANCE CHANNEL
FLOW
0.5W
W
PRIMARY
SECONDARY

B. Multiple entrance

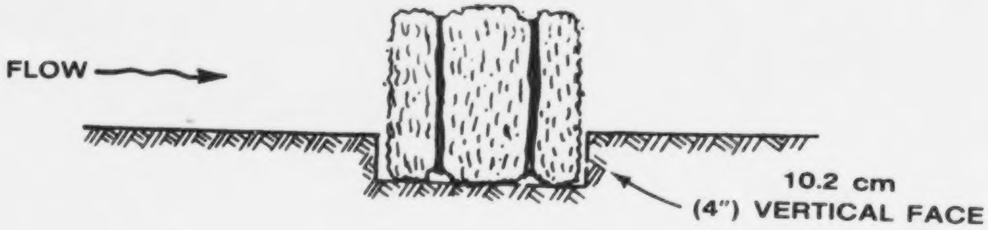
Figure 31. Multiple inlets by inlet channel branching.

Pond Modifications

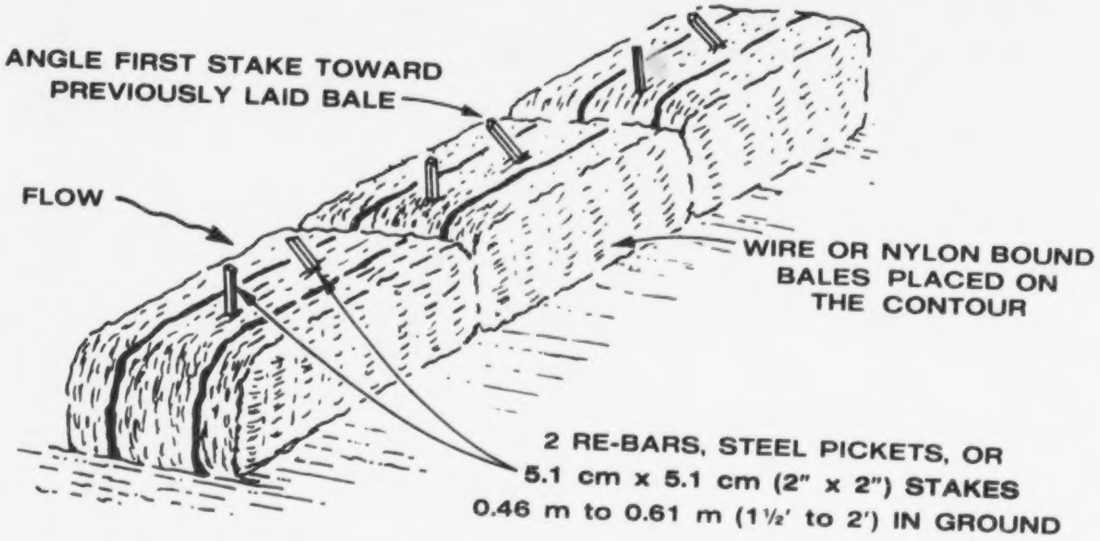
Physical modifications applicable to the main body of a sediment pond are limited to two basic concepts:

1. Compartmentalization of the basin to induce staged settling

2. Size and shape modifications


FLOW
10.2 cm
(4") VERTICAL FACE

Embedding Detail


ANGLE FIRST STAKE TOWARD PREVIOUSLY LAID BALE
FLOW
WIRE OR NYLON BOUND BALES PLACED ON THE CONTOUR
2 RE-BARS, STEEL PICKETS, OR 5.1 cm x 5.1 cm (2" x 2") STAKES 0.46 m to 0.61 m (1½' to 2') IN GROUND

Anchoring Detail

Figure 32. Straw bale barrier.[18]

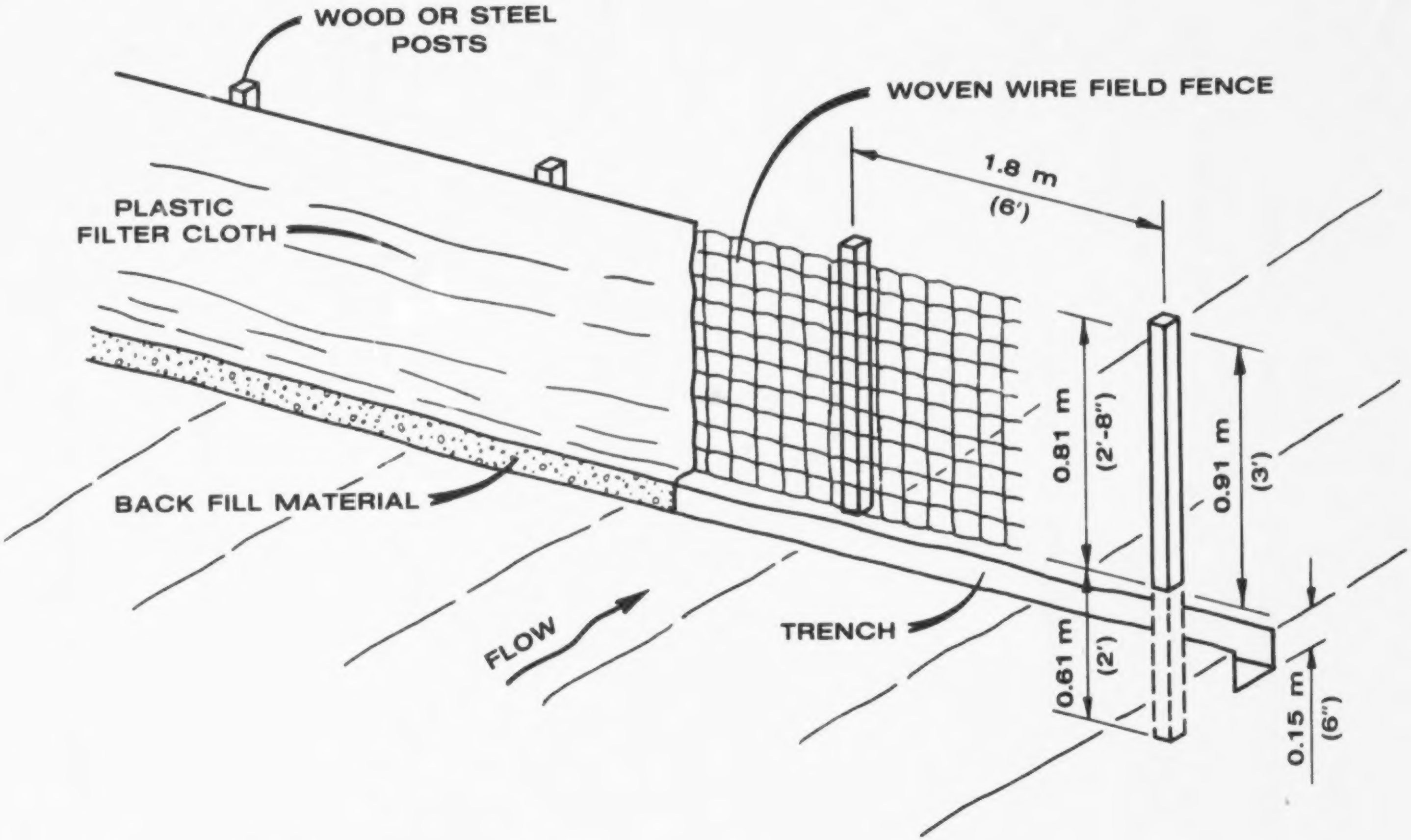

WOOD OR STEEL POSTS
WOVEN WIRE FIELD FENCE
1.8 m
(6')
PLASTIC FILTER CLOTH
0.81 m
(2'-8")
0.91 m
(3')
BACK FILL MATERIAL
FLOW
TRENCH
0.61 m
(2')
0.15 m
(6")

Figure 33. Silt fence.[19]

As stated previously, the purpose of pond modifications is to simulate ideal conditions or compensate for non-ideality. Compartmentalization compensates for non-ideality by reducing turbulence and decreasing short-circuiting, and size and shape modifications attempt to simulate ideal conditions by directing the influent through a larger percentage of the entire volume for settling, thus also reducing short-circuiting.

Compartmentalization of the Basin to Induce Staged Settling--

Compartmentalization of the body of the pond refers to either the use of separate and distinct sediment ponds in a series or the division of a single pond through the use of baffle walls. The benefit of the use of this concept is that a staged settling of suspended solids will occur. The solids having a higher settling velocity (heavier particles) will settle in the first pond or settling area with the final pond or area acting as a polishing unit to remove the remaining finer grained sediment. By taking advantage of this technique, the majority of sludge removal and disposal will take place during maintenance of the first sediment pond, or pond segment, while maintenance performed on the final pond will be minimized. As stated above, compartmentalization of a single pond can be accomplished through the use of a baffle wall constructed of wood or other suitable material placed at a position, approximately one-third of the total length of the pond from the inlet, so that a larger more quiescent compartment is formed as a final section for fine-grained sediment removal.

When designing series settling ponds, the following factors must be considered:

1. Required total sediment storage for all ponds may be considered additive;
2. Inlet and outlet structures must be sized independently and must consider the total drainage area of each pond, including the outflow from previous ponds;
3. Required detention time for each pond must be considered in light of the hydrograph modification of upstream ponds.

Size and Shape Modifications--

The use of size and shape modifications to the body of sediment ponds refers in part to the consideration of surface area in sizing of ponds, the use of a length: width ratio criteria to determine pond shape, and alteration of depth of a pond.

In the design of sedimentation basins, many methods are available ranging from rather simple analyses to complex methods using computer modelling. Generally speaking, all methods require the input of several pieces of basic information including:

1. Determination of sediment storage volume;

2. Determination of detention volume and pond peak outflow; and

3. Determination of trap efficiency.

Determination of Sediment Storage Volume--

Current requirements of the Office of Surface Mining (OSM) specify a sediment storage volume equivalent to 0.1 acre-feet of storage for every acre of disturbed area in the watershed. If so desired, the operator may compute the volume of sediment which would be expected to be deposited in the basin. A method to compute sediment yield from a watershed is the modified universal soil loss equation (MUSLE) as developed by Williams. This equation determines the gross erosion in tons from the watershed delivered to the sediment pond.

Determination of Detention Volume--

OSM currently requires a detention volume for sediment ponds which will retain the runoff from a 10-year 24-hour precipitation event for a period of 24 hours. This detention time may be lowered to 10 hours if the operator can prove to the regulatory authority that the current effluent limitations for suspended solids can be met. The detention time may be lowered to less than 10 hours if chemical treatment is used.

After the desired detention time has been selected, the computation of required basin size is begun. To determine basin volume, an inflow hydrograph of the design storm must be computed. Several methods of hydrograph computation are available, all of which are discussed in detail in available references. After determination of the inflow hydrograph, the next step in design involves the sizing of the basin and discharge device to provide the required detention time. The gross volume of the basin may be estimated by determining the total amount of runoff from the design storm event. Ward et al, describe a simple procedure to determine the required storage for various detention times plus the peak outflow which will provide that detention time.[20] After estimation of the required storage volume and selection of an appropriate outlet device to provide the desired peak outflow rate, a reservoir routing computation should be performed to determine the outflow hydrograph. The actual detention time of the basin may then be determined by finding the time difference between the centroids of the inflow and outflow hydrographs.

Determination of Trap Efficiency--

In order to design a sediment pond for a specific trap efficiency, a design storm must be specified, the particle size distribution of the incoming sediment must be known as well as the incoming sediment load. Methods to determine trap efficiency also vary between rather simple analyses to the more complex methods, using computer simulation of basin performance. Chen describes three methods of trap efficiency computation: Brune's method; Churchill's method, and Camp's method. Camp's method is probably most familiar to design engineers and describes the relation between the settling velocity of particles being removed and the surface loading or overflow velocity of the basin. By dividing the outflow rate by the surface area of the pond (Q_o/A), the settling velocity of particles completely removed may be computed. After computing the settling velocity of the removed particles, the trap efficiency of the reservoir may be determined from the influent particle size distribution. Among the more complex methods of trap efficiency determination are those requiring computer simulation. The University of Kentucky Department of Agricultural Engineering has done extensive work in this area and has developed a computer modelling technique for sediment pond performance entitled the "DEPOSITS" model.[21] The DEPOSITS model can be used to compute the effluent sedimentgraph which will specify the concentration of suspended solids in the effluent at various times during the passage of the design event.

After determination of the sediment pond dimensions, the shape of the pond can now be determined. Modifications to the shape of a pond are done in the attempt to simulate optimum conditions. A quantitative measurement of shape is the length:width ratio of the pond surface area. A length to width ratio of 5:1 for the surface area of a sediment pond has been recommended to reduce the possibility of short-circuiting.[22] Should the terrain of the area preclude the construction of a standard rectangular pond, the 5:1 length to width ratio may be attained through the use of baffles placed in the pond. In computation of the length to width ratio of an abnormally shaped pond, the effective width (W_e) is first computed as follows:

$$W_e = \frac{A}{L}$$

A = surface area of pond

L = linear distance from point of inflow to point of outflow

Subsequently the length to width ratio may be computed as

$$L:W = \frac{L}{W}$$

If the L:W ratio is less than 5:1, then it is advised that baffles be placed for increased length of flow path. Figure 34 shows three cases where a strategically placed baffle will increase the length of flow path. In all cases of pond shape, the effective length to width ratio may be computed and used to quantify the pond's attempt to simulate ideal conditions.

An additional modification to the body of a pond concerns the profile of the depth from inlet to outlet. In previous discussion, it has been indicated that the majority of settling occurs in the first one-third of the basin. To account for this phenomenon by minimizing sludge removal requirements in this area, a sloping pond bottom is recommended, with the greater depth being at the inlet. Several advantages of this modification are obvious. The velocity of the influent will be reduced as it enters this deep area, with a greater sludge storage capacity, the frequency of sludge removal is decreased, and a shallow effluent area will allow smaller size particles to settle out. When designing a pond to include the staggered depth modification, one must also consider its affect on pond outlet structures and dewatering devices.

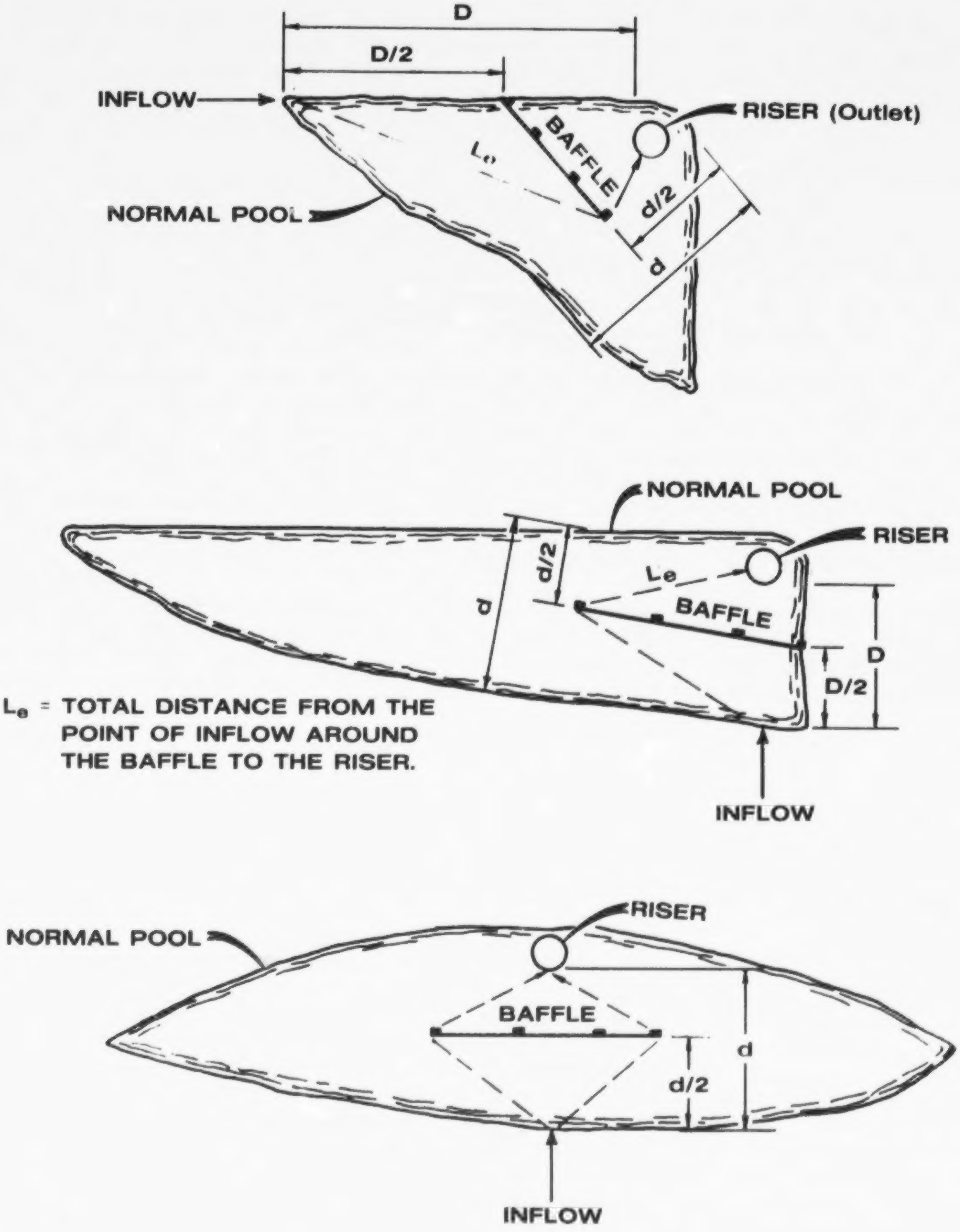
Outlet Modifications

Outlets for sediment pond currently in use include:

1. A pipe with riser barrel as used in sediment ponds WV-3 and KY-1.
2. An exit channel excavated in the embankment as in sediment ponds WV-1, WV-2, and WV-4.
3. A "flat lip" discharge as used in sediment pond PA-1.

A point outlet for a sediment pond is objectionable because of the tendency to cause short-circuiting and excessive turbulence at the point of discharge. The options to avoid single point discharges and associated short-circuiting include modification of the standard riser barrel, flared exit channels, baffled outlets, and a vegetative filter.

The use of perforated riser barrels in sediment ponds is required in some states in order to drain the pond between storm events. The use of perforations can lead to poor pond performance in that some sediment may be


D
D/2
INFLOW
RISER (Outlet)
BAFFLE
Le
d/2
d
NORMAL POOL
NORMAL POOL
RISER
d/2
Le
BAFFLE
d
D
D/2
INFLOW
RISER
NORMAL POOL
BAFFLE
d
d/2
INFLOW

L_e = TOTAL DISTANCE FROM THE POINT OF INFLOW AROUND THE BAFFLE TO THE RISER.

Figure 34. Sediment pond baffle placement to increase L:W ratio.[23]

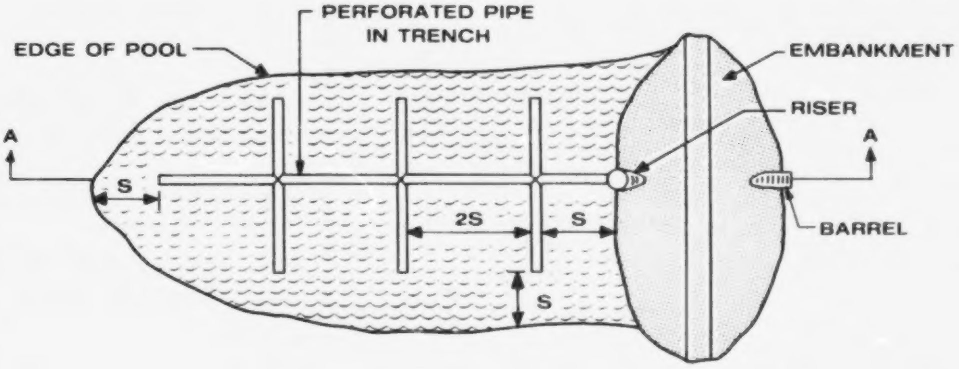
carried out of the pond through the perforations if the sediment is allowed to accumulate or if the perforations extend too far down the riser barrel. Several modifications to the conventional perforated riser barrel are available for dewatering of sediment ponds.

1. Use of a subsurface drain
2. One perforation in the riser at sediment clean-out level, with associated use of a skimming device
3. Use of a siphon arrangement to drain to the sediment - clean-out level

In the subsurface drain arrangement, a 10-cm (4-in) perforated plastic pipe network is laid in a trench in the bottom of the pond and covered with a fabric filter and sand as shown in Figure 35. The pipe is connected to the riser and the pond is dewatered through the sand filter perforated pipe arrangement by gravity. One advantage of this method is the possibility of thorough dewatering of the accumulated sediment to aid in removal and disposal. A major consideration must be, however, the added expense of installing this pipe arrangement.

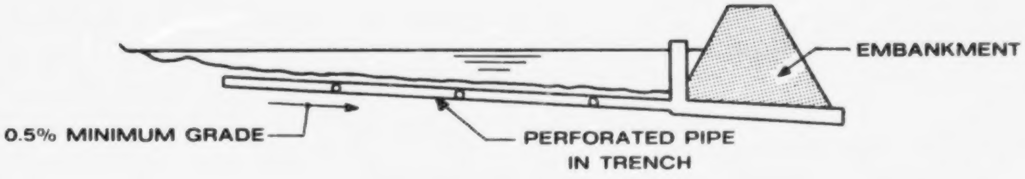
A second type of modification to the standard perforated riser barrel is the use of a single perforation at the sediment clean-out level as shown in Figure 36. This modification can be used in association with a skimming device to prevent clogging. The single perforation method is easy to construct and is capable of completely draining the pool to the sediment clean-out level; however, the perforation may clog with trash, it is not capable of skimming surface debris, and will pass a base flow out of the pond without detention if sediment storage capacity is full. The single perforation with skimmer, on the other hand, is non-clogging, fairly easy to construct, an efficient skimmer of surface debris, and is capable of draining the detention pool to clean-out level; however, it also will pass a base flow out of the pond without detention.

With the siphon methods of dewatering, as shown in Figure 37, a 10.2-cm (4-in) pipe siphon is substituted for the single perforation as described previously. In each case, the inlet to the siphon is placed at the elevation of the sediment clean-out level to facilitate drainage without removing sediment. In modification A, the siphon is primed at the sediment clean-out level as opposed to modification B, which will only prime and begin to flow when the water level reaches point A. The siphon will then continue to drain the pond until the water level reaches the sediment clean-out level and breaks the siphon. The short siphon is also an efficient skimmer of surface debris, will always drain the pond to the sediment clean-out level, and has a higher discharge capacity than the single perforation method. This technique will, however, also pass a base

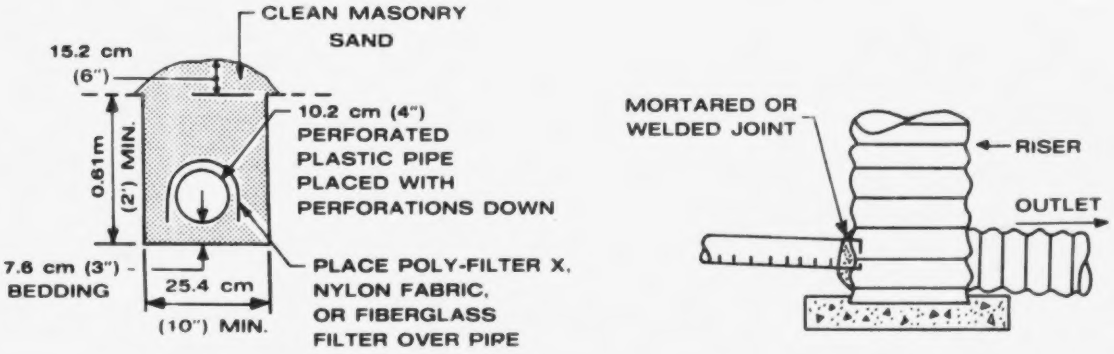

PERFORATED PIPE
IN TRENCH
EDGE OF POOL
EMBANKMENT
RISER
A
A
S
2S
S
S
BARREL

NOTE: S = 4.6 m to 7.6 m (15' to 25')

Plan


EMBANKMENT
0.5% MINIMUM GRADE
PERFORATED PIPE
IN TRENCH

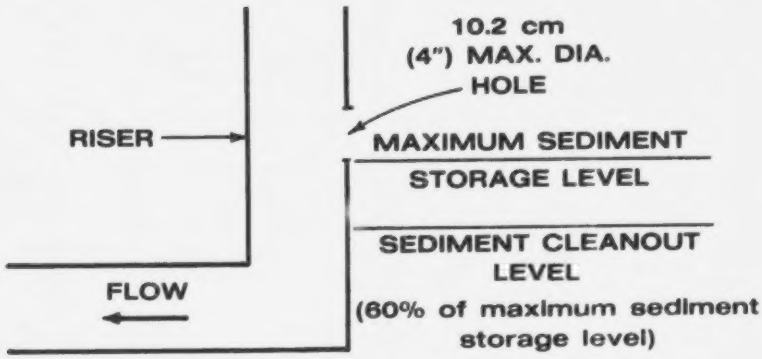
Section A-A


CLEAN MASONRY
SAND
15.2 cm
(6")
0.61m
(2') MIN.
10.2 cm (4")
PERFORATED
PLASTIC PIPE
PLACED WITH
PERFORATIONS DOWN
7.6 cm (3")
BEDDING
25.4 cm
(10") MIN.
PLACE POLY-FILTER X,
NYLON FABRIC,
OR FIBERGLASS
FILTER OVER PIPE
MORTARED OR
WELDED JOINT
RISER
OUTLET

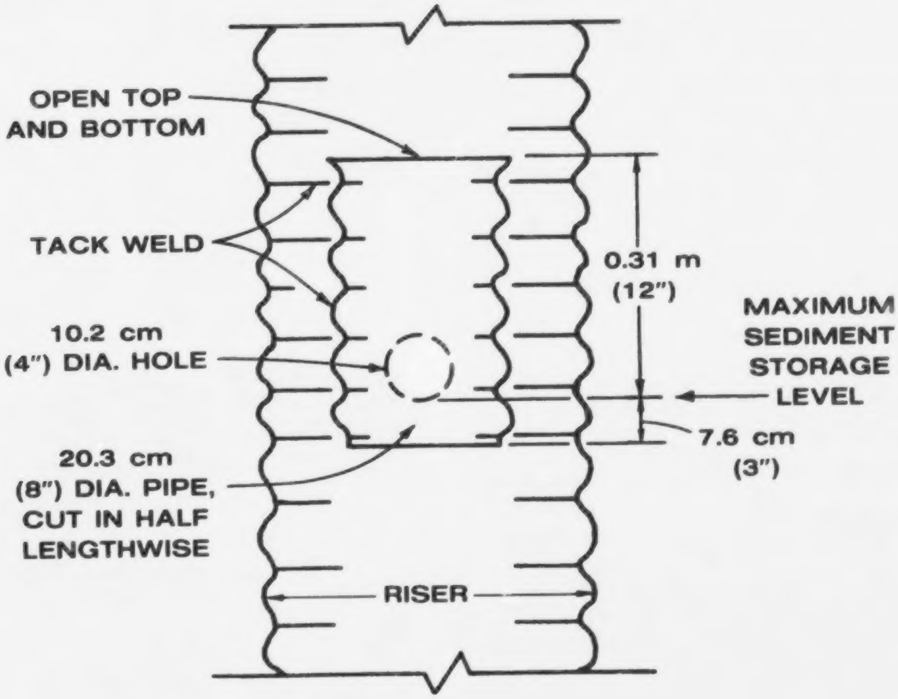
Cross-Section
Drain Pipe in Trench

Riser
Connection

Figure 35. Subsurface drain.[24]

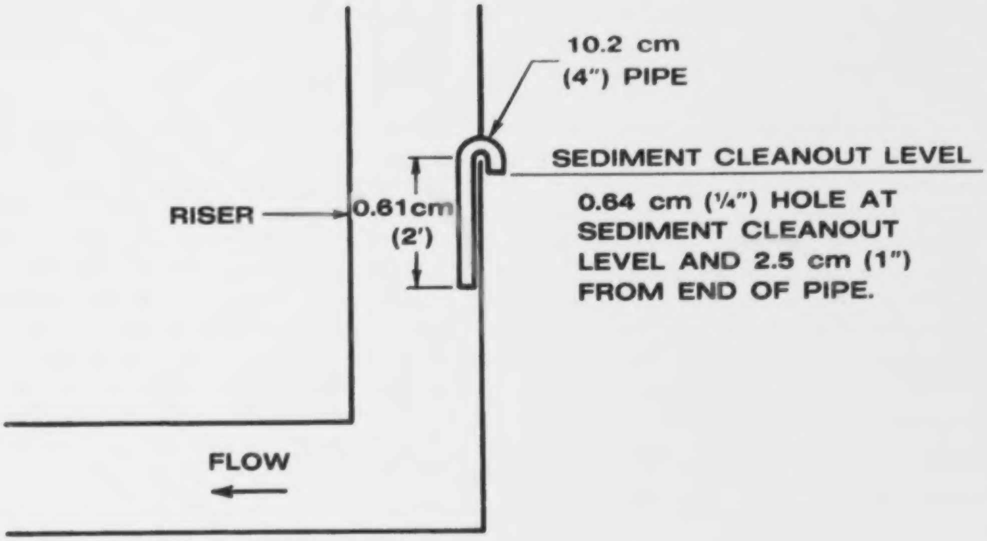

10.2 cm
(4") MAX. DIA.
HOLE
RISER
MAXIMUM SEDIMENT
STORAGE LEVEL
SEDIMENT CLEANOUT
LEVEL
(60% of maximum sediment
storage level)
FLOW

Single Perforation
(Cross Section)

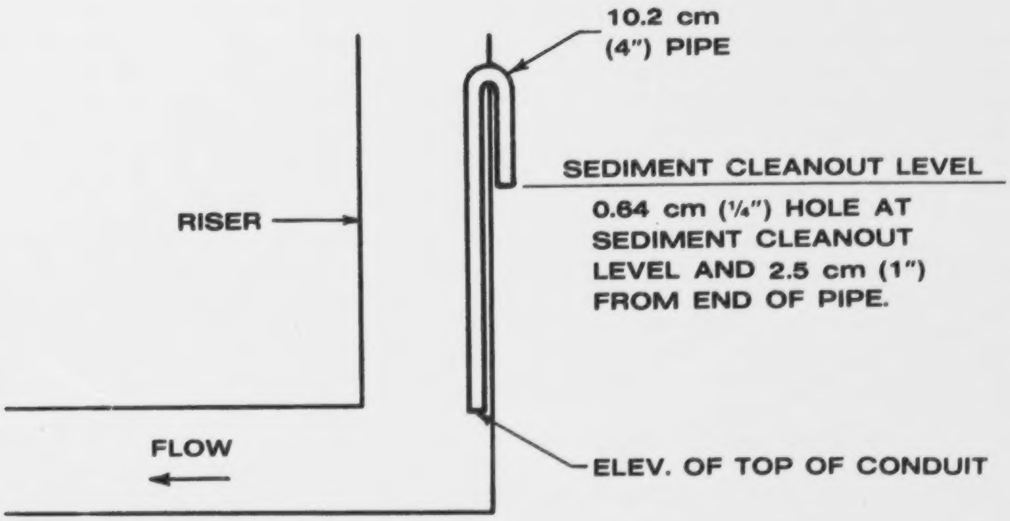

OPEN TOP
AND BOTTOM
TACK WELD
10.2 cm
(4") DIA. HOLE
20.3 cm
(8") DIA. PIPE,
CUT IN HALF
LENGTHWISE
0.31 m
(12")
MAXIMUM
SEDIMENT
STORAGE
LEVEL
7.6 cm
(3")
RISER

Single Perforation With Skimmer
(Elevation)

Figure 36. Single perforation of riser barrel.[25]


10.2 cm
(4") PIPE
SEDIMENT CLEANOUT LEVEL
0.64 cm (¼") HOLE AT
SEDIMENT CLEANOUT
LEVEL AND 2.5 cm (1")
FROM END OF PIPE.
RISER
0.61cm
(2')
FLOW

A. Short siphon cross-section.


10.2 cm
(4") PIPE
SEDIMENT CLEANOUT LEVEL
0.64 cm (¼") HOLE AT
SEDIMENT CLEANOUT
LEVEL AND 2.5 cm (1")
FROM END OF PIPE.
RISER
FLOW
ELEV. OF TOP OF CONDUIT

B. Long siphon cross-section.

Figure 37. Siphon dewatering methods.[26]

flow without storage of water. The long siphon method has the added advantage of being able to store water in the pond above the sediment cleanout level because of its siphon priming requirement.

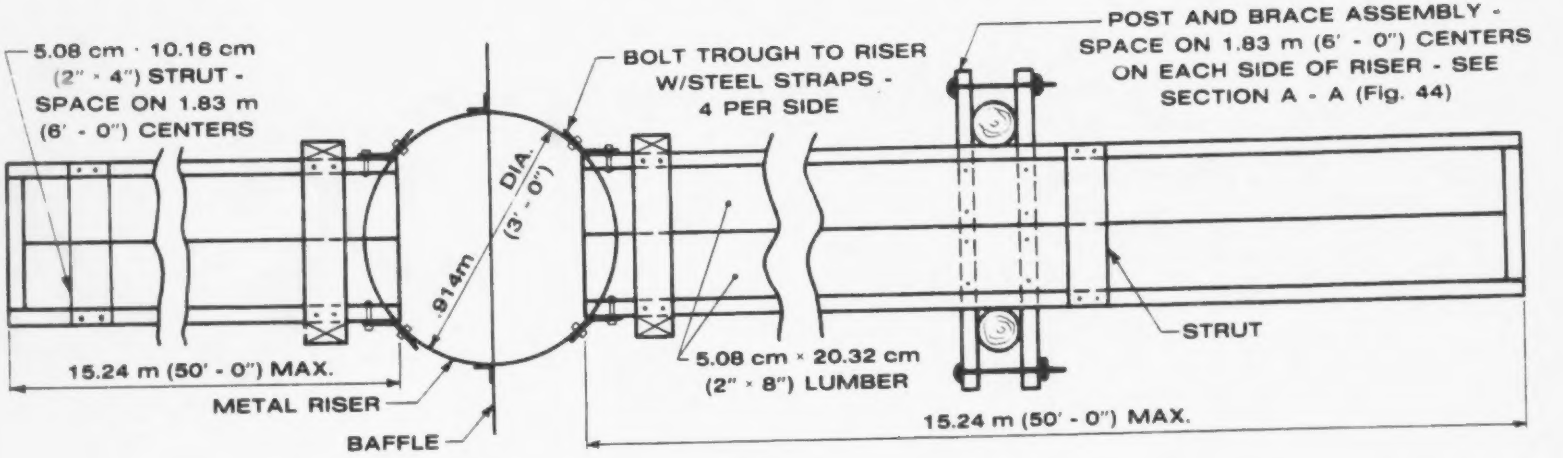
One alternate choice to the standard riser barrel is the use of a weir trough connected to the outlet structure as shown in Figure 14. This photograph shows the use of a wooden weir trough as the primary outlet leading to the riser barrel. The weir trough is supported along its length by 10.2 cm (4 in) posts with braces located on 1.8 m (6 ft) centers. The trough itself is constructed of treated 5.1 cm x 15.2 cm (2 in x 6 in) lumber to form a trough 30.5 cm (12 in) wide by 14.0 cm (5 1/2 in) deep. The braces are placed at least 0.92 m (3 ft) into the bottom of the pond, the trough is mounted on the brace with a slope to the riser of 0.83 cm/m (1 in/10 ft) and the lumber is thoroughly coated with roofing tar to protect against weathering. Figures 38 and 39 indicate the details of the trough. The main advantage of using this weir type of outlet is the elimination of turbulence at the discharge and the possibility of scouring previously settled solids from the pond.

All of the previously discussed modifications to the standard riser barrel discharge have specific advantages and disadvantages related to each technique. The decision to use or not use the techniques must be made on an objective basis weighing the possible improvement of pond efficiency vs additional cost.

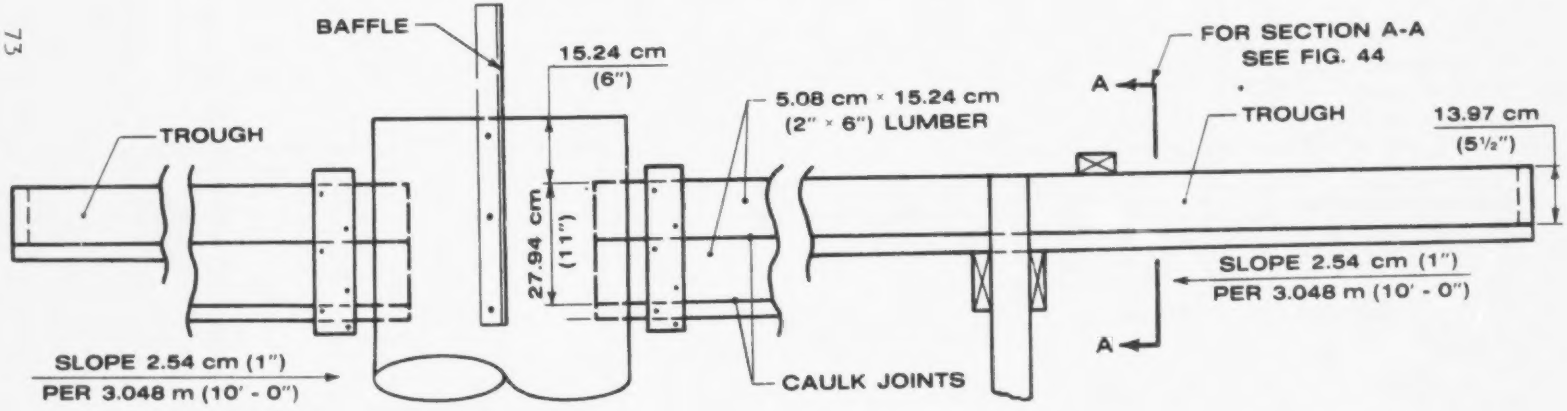
In modification of the outlets of excavated ponds and excavated sediment dams, the primary objective is to spread the outflow over a large an area as possible. This can be done by using a flared entrance to the exit channel similar to the flared entrance channel described previously. One of the major advantages of this technique is the reduction of short-circuiting associated with a restricted outlet in addition to the reduction in effluent velocity with associated turbulence.

Should the construction of a flared effluent channel be undesirable, a strategically placed baffle, shown in Figure 40, placed in front of the entrance to the exit channel may reduce short-circuiting. An additional modification to the exit channel would be the use of multiple outlets rather than one single outlet. An advantage to this technique would also be the reduction of short-circuiting in the pond.

A final method of pond outlet modification is the use of a vegetative filter of marsh plants. Recent research in Poland has shown that the flow of runoff from mine areas through an area covered with bog and peat vegetation contributes to the removal of suspended solids to a great extent. This removal ability has been determined for such plants as the common reed, yellow flag, sweet flag, common rush, and redge. This vegetative filter would be used as a polishing pond prior to final discharge. Its applicability would be limited to a relatively flat terrain where a large surface area would be available for a very quiescent movement of flow in the basin.


5.08 cm · 10.16 cm
(2" × 4") STRUT -
SPACE ON 1.83 m
(6' - 0") CENTERS
BOLT TROUGH TO RISER
W/STEEL STRAPS -
4 PER SIDE
POST AND BRACE ASSEMBLY -
SPACE ON 1.83 m (6' - 0") CENTERS
ON EACH SIDE OF RISER - SEE
SECTION A - A (Fig. 44)
DIA.
.914m
(3' - 0")
STRUT
5.08 cm × 20.32 cm
(2" × 8") LUMBER
15.24 m (50' - 0") MAX.
METAL RISER
BAFFLE
15.24 m (50' - 0") MAX.

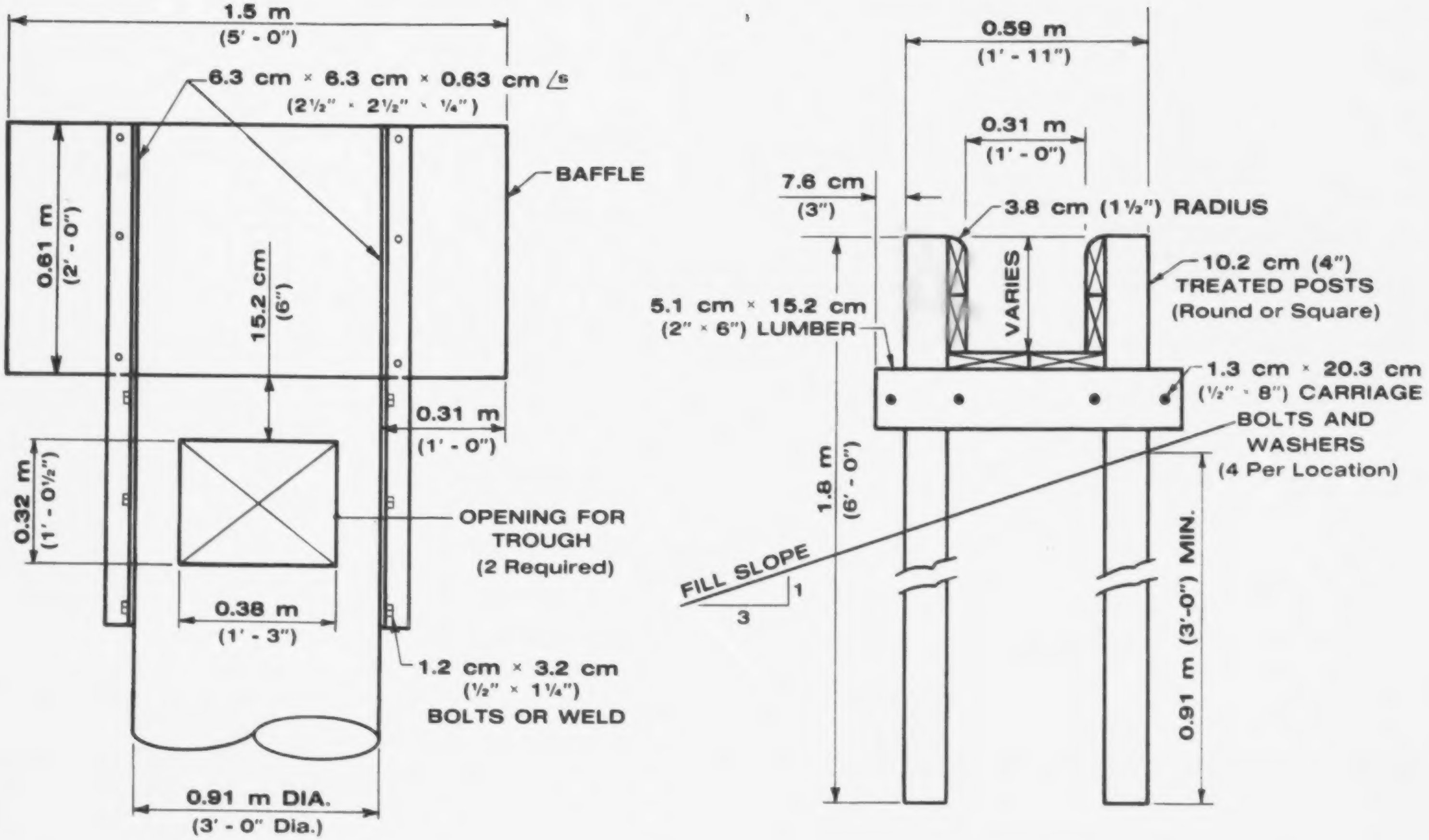
Plan


BAFFLE
15.24 cm
(6")
5.08 cm × 15.24 cm
(2" × 6") LUMBER
FOR SECTION A-A
SEE FIG. 44
A
TROUGH
13.97 cm
(5½")
TROUGH
27.94 cm
(11")
SLOPE 2.54 cm (1")
PER 3.048 m (10' - 0")
A
SLOPE 2.54 cm (1")
PER 3.048 m (10' - 0")
CAULK JOINTS

Elevation

Figure 38. Riser and trough plan and elevation.[27]

NO SCALE


1.5 m
(5' - 0")
6.3 cm × 6.3 cm × 0.63 cm ∠s
(2½" × 2½" × ¼")
BAFFLE
0.61 m
(2' - 0")
15.2 cm
(6")
0.31 m
(1' - 0")
0.32 m
(1' - 0½")
OPENING FOR
TROUGH
(2 Required)
0.38 m
(1' - 3")
1.2 cm × 3.2 cm
(½" × 1¼")
BOLTS OR WELD
0.91 m DIA.
(3' - 0" Dia.)
0.59 m
(1' - 11")
0.31 m
(1' - 0")
7.6 cm
(3")
3.8 cm (1½") RADIUS
VARIES
10.2 cm (4")
TREATED POSTS
(Round or Square)
5.1 cm × 15.2 cm
(2" × 6") LUMBER
1.3 cm × 20.3 cm
(½" × 8") CARRIAGE
BOLTS AND
WASHERS
(4 Per Location)
1.8 m
(6' - 0")
FILL SLOPE
1
3
0.91 m (3'-0") MIN.

Side Elevation

Section A-A

Figure 39. Riser and trough details.[28]
NO SCALE

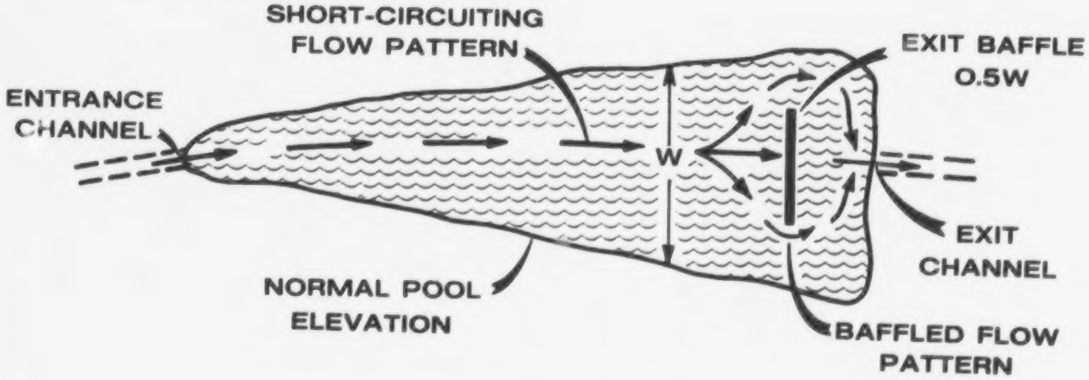


Figure 40. Exit baffle.

Summary

Physical modifications to sediment ponds, as described in the previous section, may be undertaken in various phases of pond construction. In order for a pond designer to make a decision regarding the selection of a specific modification, several factors must be considered. The economics of the design must be reviewed in light of any improvements or benefits that may be realized. The required maintenance schedule must be considered as well as the applicability of the modification to the local terrain. A summary of the suggested physical modifications has been compiled in Table 9, and includes an estimated cost of each structure, required maintenance, any improvements or benefits that may be realized and applicability of each respective modification. A designer may refer to this table for assistance in selecting a method to improve performance of a standard settling basin. It should be noted that no one method is recommended over another as each respective improvement method must be judged based upon the characteristics of each specific site.

Table 17 has been subdivided into four descriptive sections. The initial section is titled, Estimated Additional Cost. In this section, the cost figures that are presented were developed based upon readily available information. For each modification, an estimate of manpower, equipment, and material was made which would be required in excess of normal pond construction requirements. The second section, titled Maintenance Requirements, describes, in general terms, the frequency of removing settled matter and any maintenance of the structure. The Improvements/Benefits section characterizes improvements to settling efficiency by detailing action of each modification. Finally, the applicability of each modification is detailed to describe its placement depending upon variations in local terrain.

TABLE 17. SUMMARY OF SEDIMENT POND PHYSICAL MODIFICATIONS

Inlet modifications	Estimated additional costs	Maintenance requirements	Advantages/ disadvantages	Applicability
Log and pole structure	\$500	Periodic sediment removal	- Velocity reduction - Removes 5% of suspended solids	- In natural drainway - Steep sloped area
Rock check dam	\$300	Periodic sediment removal	- Velocity reduction - Removes 5% of suspended solids 29	- In natural drainway - Steep sloped area
Dumped rock at inlet	\$150	Generally not required	- Velocity reduction	- All locations
Silt fence	\$2.10/ft^2	Periodic sediment removal	- Filters fine grained sediment - Velocity reduction	- Small drainage areas - Alongside natural or constructed drainways
Straw bale dike	\$3.00/LF	Life expectancy of three months	- Velocity reduction - Filtration - Removes 5% of suspended solids	- Very small drainage areas - Along natural or constructed drainways
Multiple inlets	\$220	Generally not required	- Inlet flow distribution	- On constructed drainways
Inlet apron	\$450	Generally not required	- Inlet flow distribution	- On constructed drainways
Baffle at inlet	\$140	More frequent sediment removal	- Velocity reduction - Inlet flow distribution - Reduction of short-circuiting	- All locations

(continued)

TABLE 17. (continued)

Configuration modification	Estimated additional costs	Maintenance requirements	Advantages/ disadvantages	Applicability
Series settling ponds	Site specific	Majority of sediment removal in first pond	- Staged settling	- Flat to rolling terrain
Divided settling pond	$500	Majority of sediment removal in first pond	- Staged settling	- All locations
Additional pond storage	Site specific	Less frequent sediment removal	- Longer detention times	- Flat to rolling terrain
Additional surface area	Site specific	None	- Removes smaller particles	- Flat to rolling terrain
Baffle for L:W ratio	$140	Generally not required	- Increased detention time - Reduction of short-circuiting	- All locations
Staggered depth	None	Majority of sediment removal at inlet area	- Less frequent sediment removal	- All locations

(continued)

TABLE 17. (continued)

Outlet modifications	Estimated additional costs	Maintenance requirements	Advantages/ disadvantages	Applicability
Weir trough	$450	Generally not required	- Reduces effluent velocity - Reduces turbulence	- Ponds with riser
Subsurface drain	$450	Generally not required	- Can totally dewater pond - Easily clogged	- All locations
Single perforation in riser and with skimming device	$ 36	Generally not required	- Non-clogging - Drains to sediment level	- Ponds with riser
Riser barrel with siphon	$ 50	Generally not required	- Skims debris - Drains to sediment level - Higher discharge capacity	- Ponds with riser
Flared exit channel	$450	Generally not required	- Reduction of short-circuiting - Reduction of turbulence	- Excavated ponds
Baffled exit channel	$170	Generally not required	- Reduction of short-circuiting	- All locations
Multiple outlet	$220	Generally not required	- Reduction of short-circuiting	- All locations
Vegetative filter	$160	Periodic sediment removal	- Polishing of effluent	- Flat or rolling terrain

EVALUATION OF COAGULANT USAGE

As discussed in the suspended solids removal section of the report, the settling velocity of a particle decreases dramatically as the size of the particle decreases. Conventional sedimentation techniques will generally not remove particles less than ten microns in diameter and another alternative technique must be used. One alternative technique is the use of chemical coagulants to cause the individual particles to agglomerate and settle as larger particles. As an additional phase of this study, the possible use of coagulants to improve the performance of surface mine sedimentation ponds was investigated.

Coagulant Testing Program

The evaluation of commercially available coagulants was conducted in a four-phase effort as follows:

1. Initial contact with manufacturers to determine coagulant characteristics;
2. Preliminary laboratory testing of 30 to 40 coagulants;
3. Bench-scale treatability test of 6 to 10 coagulants chosen from step 2; and
4. Evaluation of the potential environmental impacts of coagulant use.

Step one involved a survey of coagulant manufacturers to tabulate specific physical and chemical characteristics and an elimination process to choose 30 to 40 coagulants to use in preliminary testing. Step two consisted of jar tests to determine the effectiveness of each coagulant in the removal of turbidity and suspended solids from water samples from the influent of each model sediment pond. From step two data, a list of 6 to 10 effective coagulants was chosen for a bench-scale treatability test during Step 3. The final phase of the laboratory study was to determine the potential environmental impacts occurring as the result of coagulant usage.

Step One - Initial Coagulant Manufacturer Survey--

The first step in the coagulant testing program was to contact manufacturers of commercially available coagulants to obtain information on their products and a sample for laboratory evaluation. A total of eighty manufacturers were contacted during the survey to obtain preliminary data. Samples of 144 commercially available coagulants were received along with detailed data on the physical and chemical characteristics of each. A listing of the manufacturers contacted and the trade name identification of each coagulant can be found in the Appendix - Table A-1.

After receiving and tabulating the chemical and physical characteristics of the 144 coagulants, a screening and elimination process was begun to choose a group of 30 to 40 coagulants to use for preliminary testing on influent samples from the six model sediment ponds. The 144 coagulants were screened and subjected to a process of elimination based upon several criteria including:

- Operating characteristics

    - Chemical composition
    - Toxicity
    - Range of applicability

- Method of introduction to treatment system

- Reaction time requirements

- Sludge characteristics

- Economics

From this list of 144 organic coagulants, thirty-one plus alum and lime were chosen for the second phase of coagulant evaluation. The thirty-three coagulants have been tabulated with their specific physical and chemical characteristics in Table A-2 located in the Appendix.

A listing of the selected coagulants includes the following:

Code #	Manufacturer	Trade Name
3M	Allied Colloids, Inc.	Percol 727
6A	American Cyanamid	Magnifloc 573C
6B	American Cyanamid	Magnifloc 577C
6C	American Cyanamid	Magnifloc 581C
6D	American Cyanamid	Magnifloc 585C
6E	American Cyanamid	Magnifloc 587C
6F	American Cyanamid	Magnifloc 589C
15A	Buckman Laboratories	Hicat 1
17A	Calgon Corp.	Cat-floc
17B	Calgon Corp.	Cat-floc T
17C	Calgon Corp.	Cat-floc T-1
17H	Calgon Corp.	M-502
22A	Cities Service Company	Ferri-floc
30A	Dow Chemical Co.	Separan MG-200
30B	Dow Chemical Co.	Separan MG-700
30C	Dow Chemical Co.	XD-30150.00
30D	Dow Chemical Co.	SC-30204
31A	Drew Chemical Co.	Amerfloc 485

Code #	Manufacturer	Trade Name
44B	Haviland Product Co.	Poly Floc C
46A	Hercules Inc.	Hercofloc 812
46B	Hercules Inc.	Hercofloc 818
46C	Hercules Inc.	Hercofloc 821
46D	Hercules Inc.	Hercofloc 831
46E	Hercules Inc.	Hercofloc 849
46F	Hercules Inc.	Hercofloc 874
61F	Nalco Chemical Co.	Nalco 7107
61H	Nalco Chemical Co.	Nalco 7134
61K	Nalco Chemical Co.	Nalco 8851
61L	Nalco Chemical Co.	Nalco 8852
71C	Rohm & Haas Co.	Primafloc C-7
315	American Cyanamid	Superfloc 315

Step Two - Preliminary Laboratory Testing--

The second step in the evaluation of the coagulants consisted of a laboratory jar test of each coagulant on all six of the model sediment pond water samples. Standard jar tests were preformed by adding 500 ml of the test water to 600 ml beakers and placing on a six position variable speed multiple paddle stirrer. Various dosages of each coagulant were added to the beakers followed by a rapid mix period of stirring the test water at 100 rpm for two minutes followed by a slow mix period of stirring at 50 rpm for five minutes. In addition to the coagulated samples, a control sample to which no coagulant was added was tested. After the slow mix period was completed, the water sample was allowed to settle undisturbed for three hours to observe floc formation, size of floc, sludge volume, settling rates, and any other noticeable characteristics. After settling for three hours, the supernatant from each beaker was decanted and analyzed for pH, turbidity, and suspended solids. The data for each model sediment pond water sample are recorded in Table A-3 located in the Appendix. Figures 41 through 45 graphically depict the percent removal of turbidity and suspended solids for the thirty-three coagulants tested at optimum dosage. A summary of the observations regarding the treatability of each mine water is as follows:

Coagulation of PA-1 Influent

- Control sample and all coagulated samples had a sludge volume of approximately 1%.
- All liquid coagulants formed small-flocced particles.
- All solid coagulants formed large-flocced particles other than 46A.

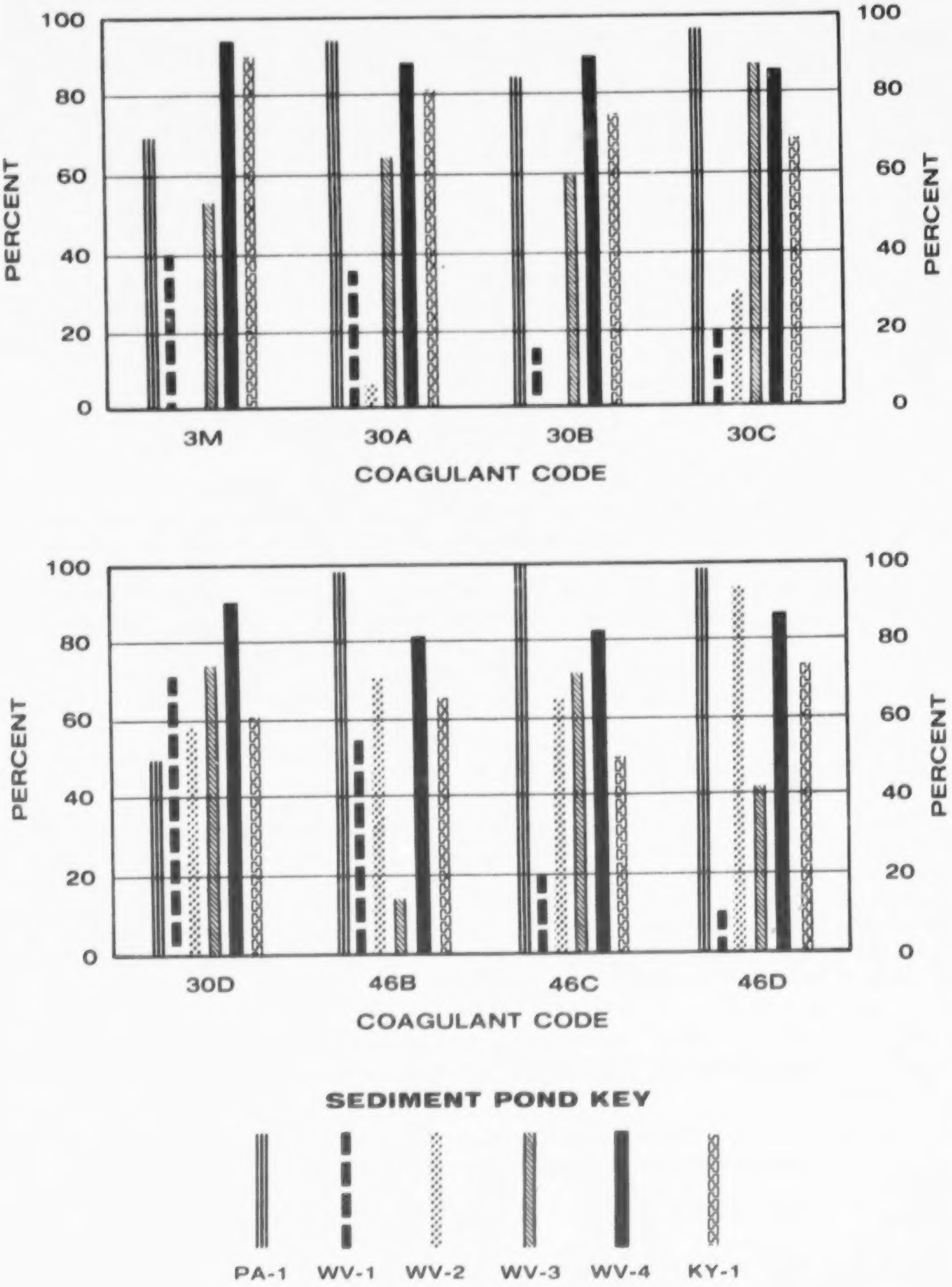


Figure 41. Suspended solids removal by anionic coagulants.

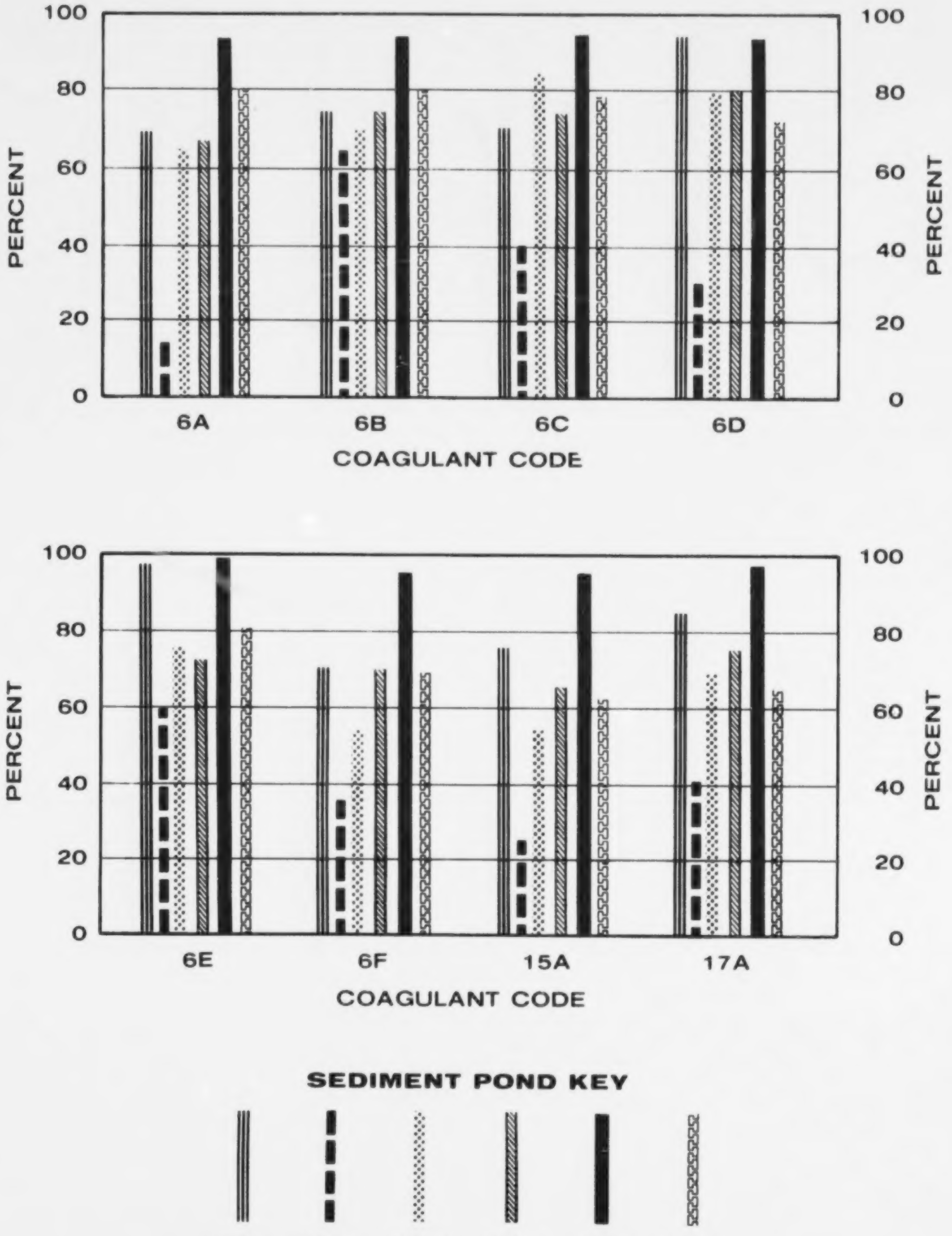


Figure 42. Suspended solids removal by cationic coagulants.

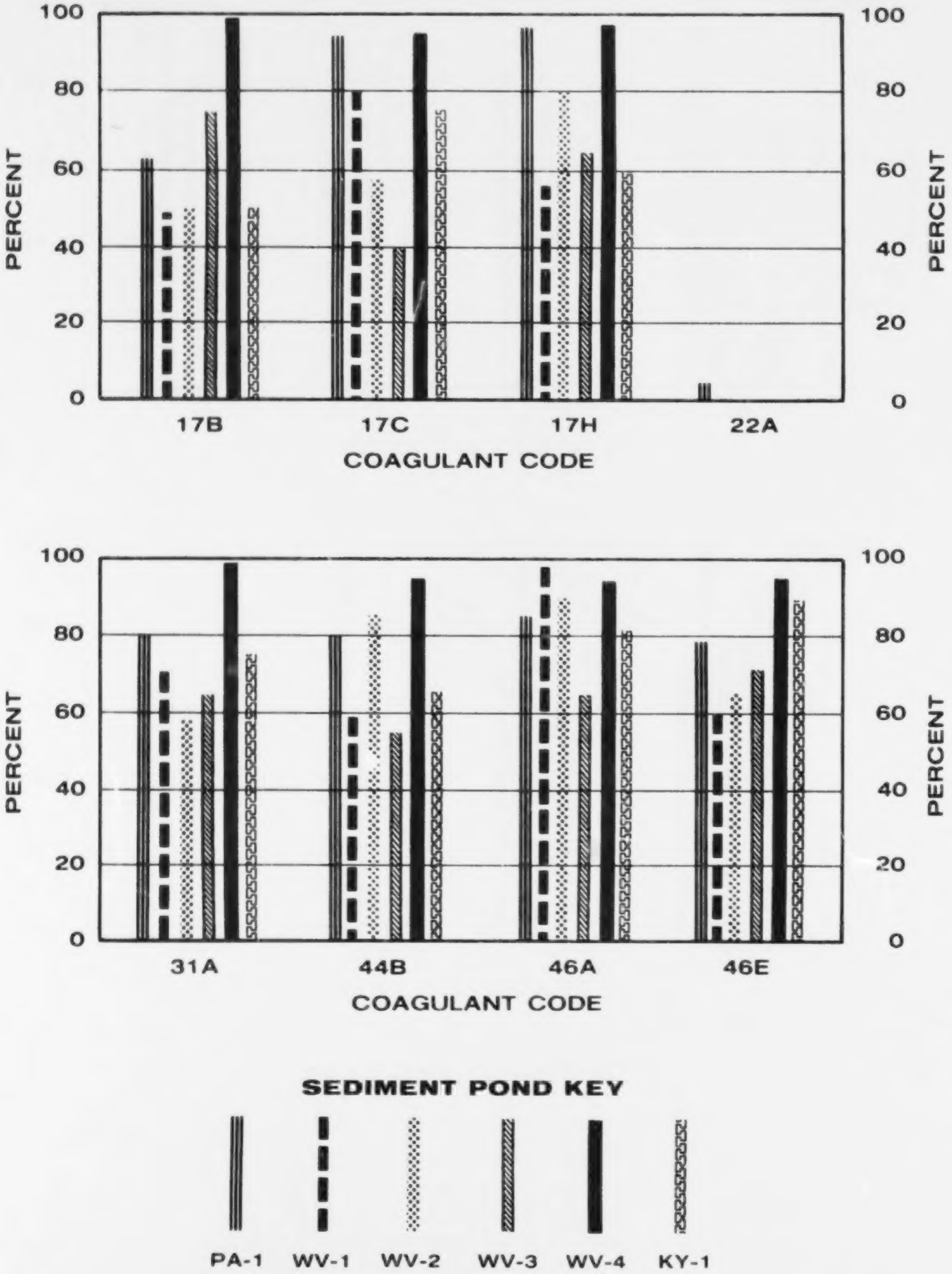


Figure 42. (continued)

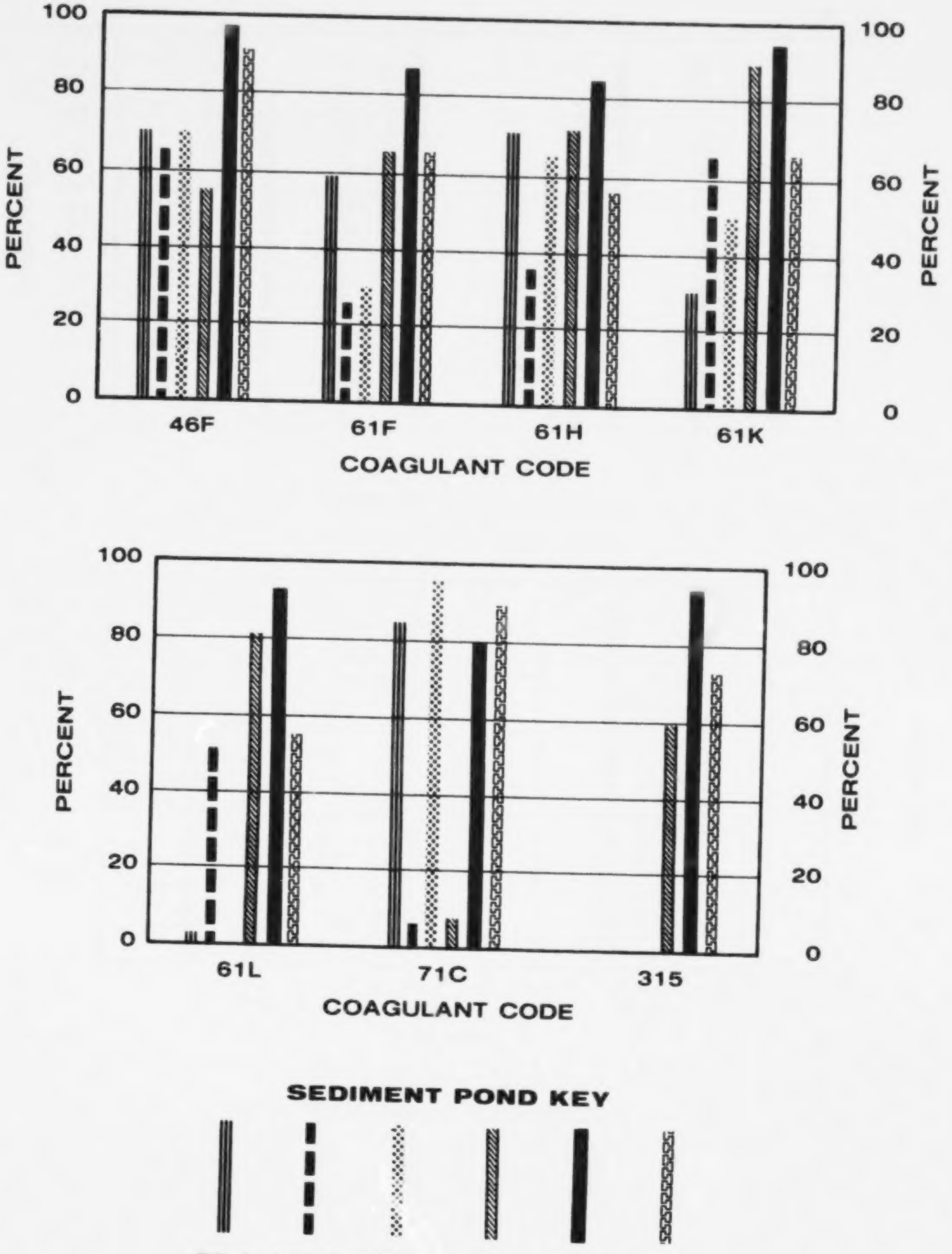
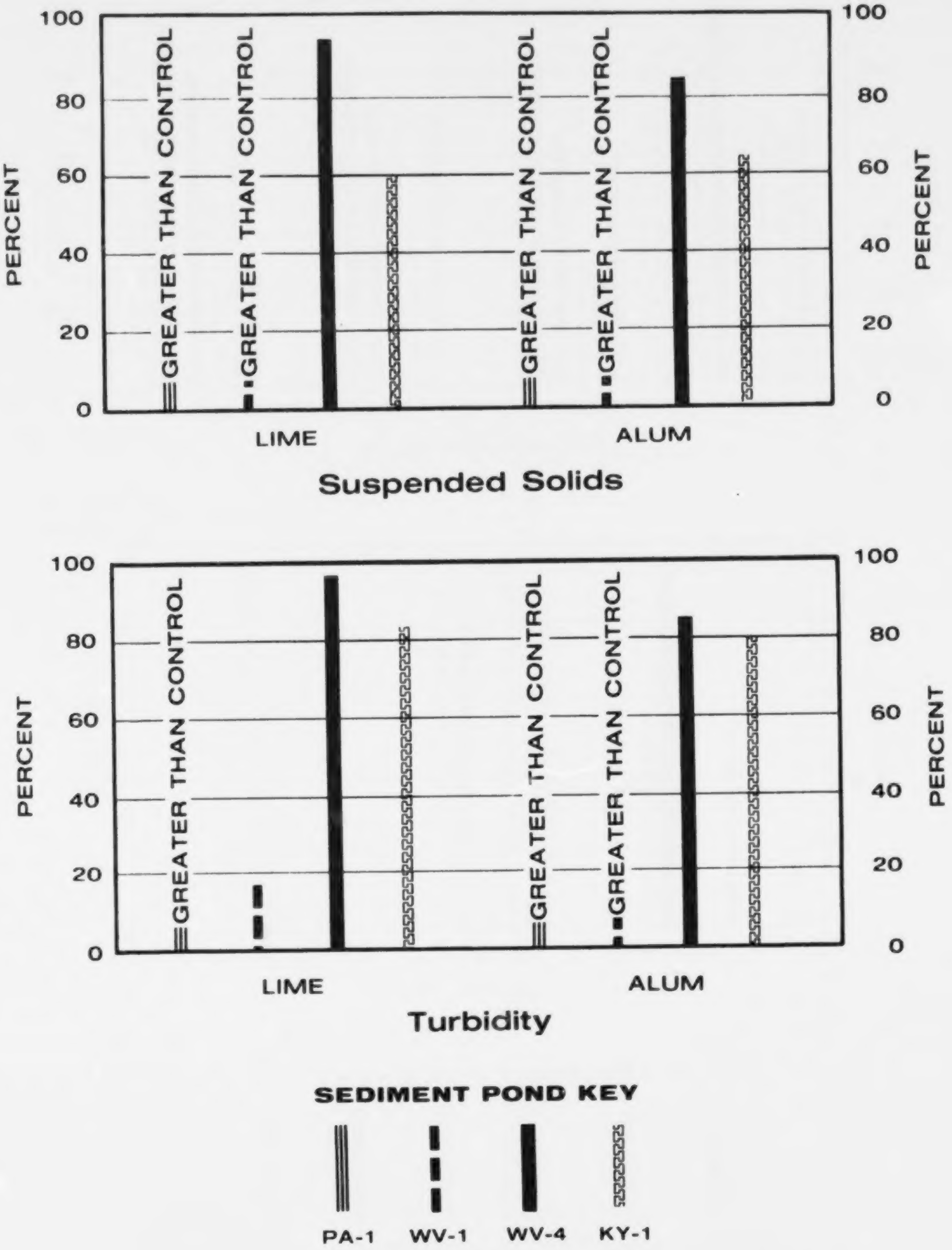


Figure 42. (continued)



Suspended Solids

Turbidity

Figure 43. Suspended solids and turbidity removal by lime and alum.

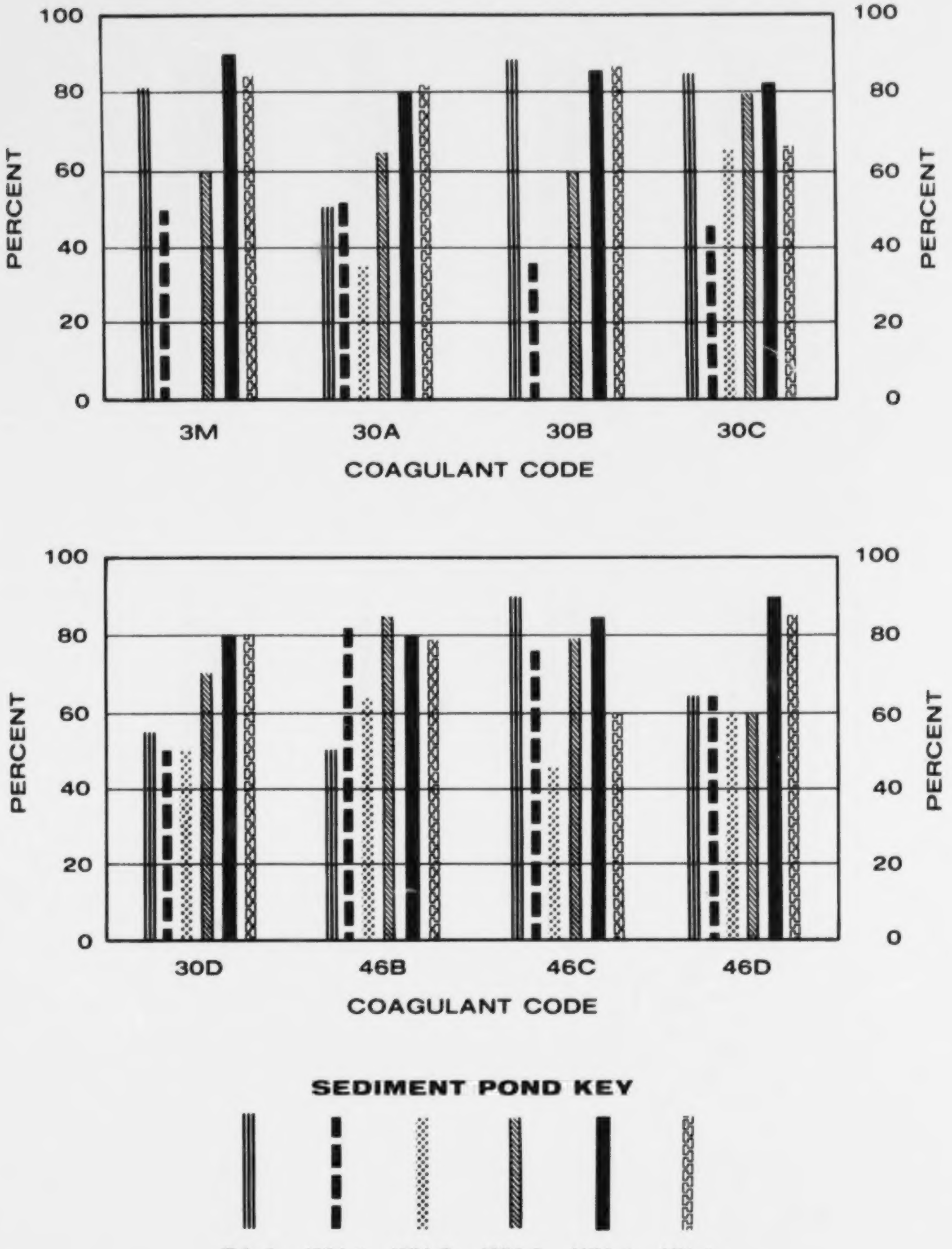


Figure 44. Turbidity removal by anionic coagulants.

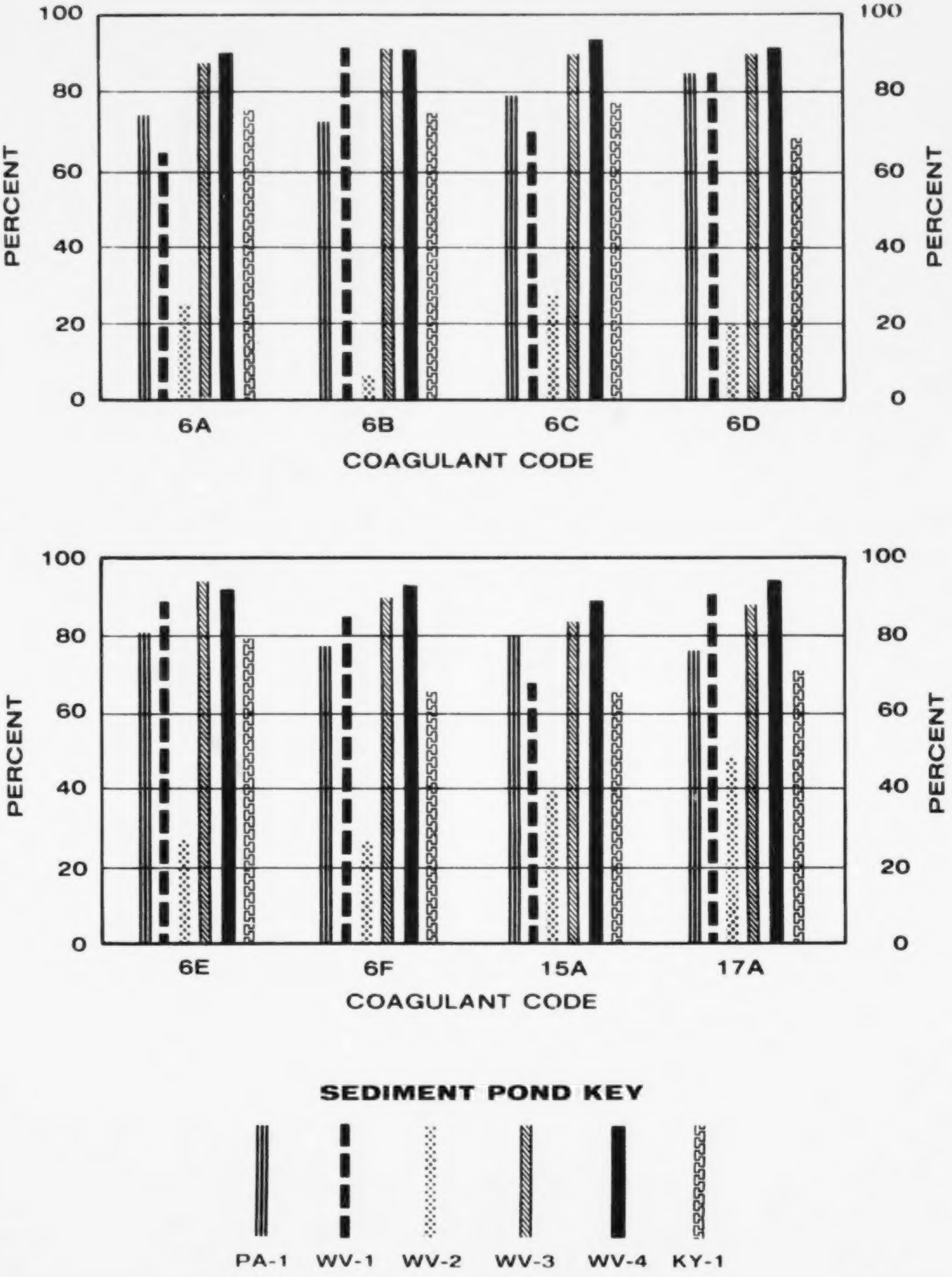


Figure 45. Turbidity removal by cationic coagulants.

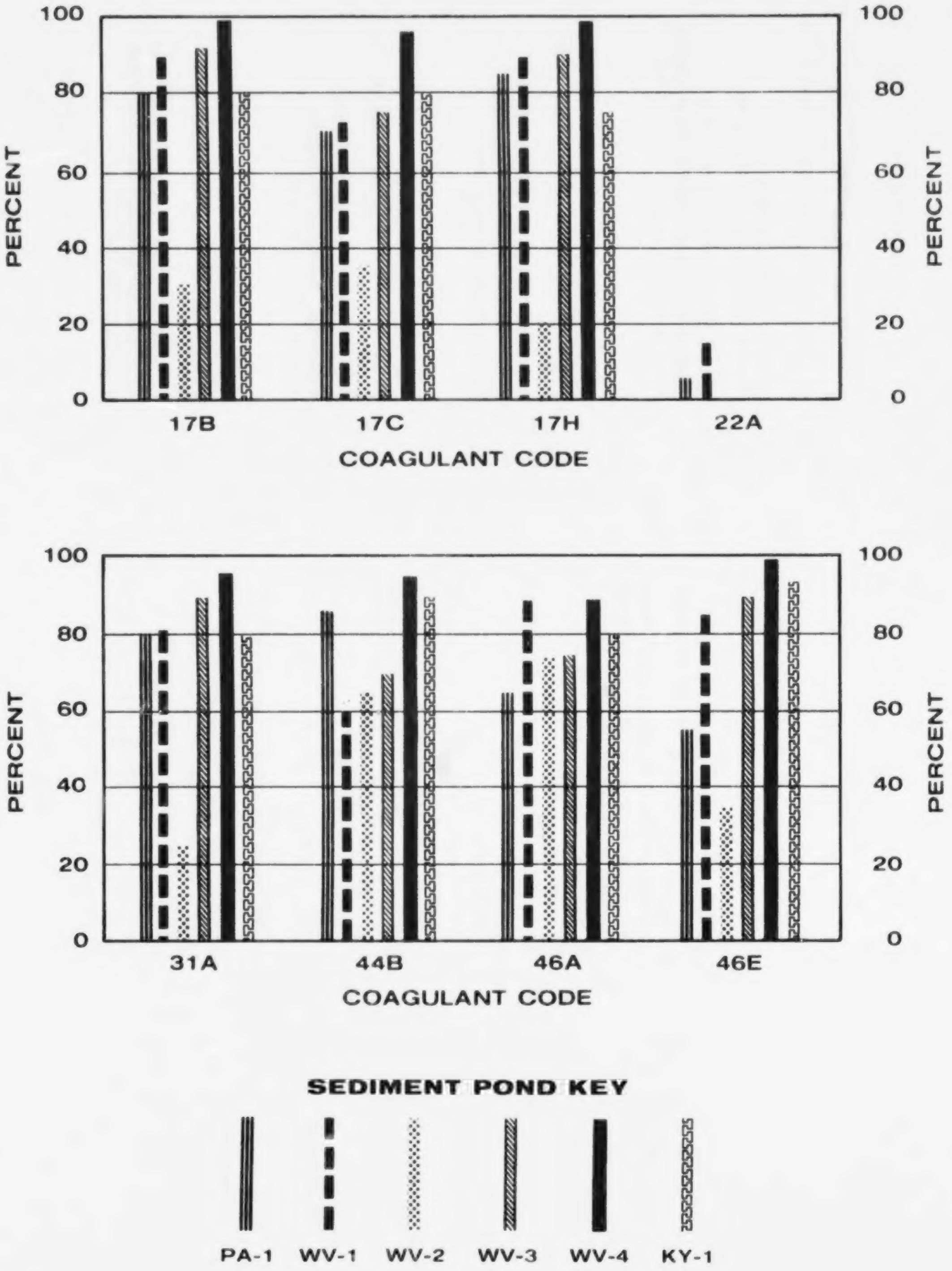


Figure 45. (continued)

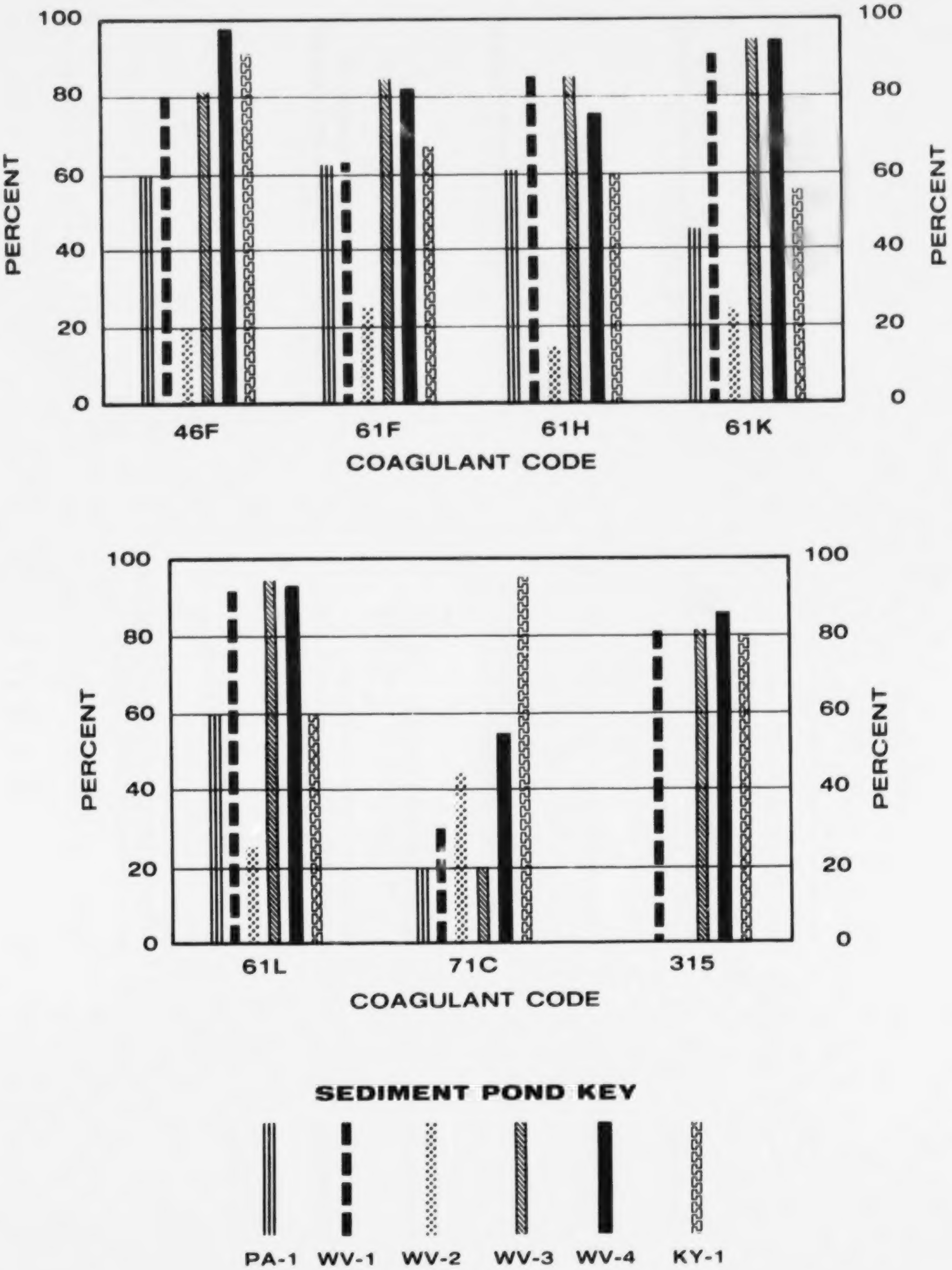


Figure 45. (continued)

- Coagulant 46B formed small-flocced particles with a 0.5 ppm dosage, medium-flocced particles with a 1.0 ppm dosage, and large-flocced particles with a 1.5 ppm dosage.

- Coagulant dosage had very little effect on pH.

Coagulation of WV-1 Influent

- Control sample and all coagulated samples had a sludge volume of 1-2%.

- All liquid coagulants formed small-flocced particles.

- All solid coagulants formed large-flocced particles.

- Increasing the coagulant dosage caused slight elevation of the pH.

Coagulation of WV-2A Influent

- All sludge volumes were less than 0.5%.

- Most liquid coagulants formed small-flocced particles.

- Most solid coagulants formed large-flocced particles.

- Coagulant dosage had very little effect on pH.

Coagulation of WV-3 Influent

- All sludge volumes were in the range of 2-4%.

Coagulation of WV-4 Influent

- Larger dosages of coagulant were required to cause coagulation and settling.

- Sludge volumes were approximately 2-5%.

- Although most coagulants removed large percentages of suspended solids and turbidity, most of the supernatants did not meet discharge limitations, using up to 5 ppm of coagulant.
- An additional test was performed using three coagulants at a higher dosage with a longer settling time, the results are listed in Table 18.

TABLE 18. EXTENDED SETTLING TIME RESULTS

Coagulant	Dosage (mg/l)	Suspended solids (mg/l) 3 hr.	Suspended solids (mg/l) 24 hr.	% Removal of suspended solids after 24 hours
315	5.0	44	18	98
315	10.0	--	8	99
31A	5.0	21	17	99
31A	10.0	--	16	99
46E	5.0	48	23	98
46E	10.0	--	12	99

Coagulation of KY-1 Influent

- Sludge volumes were less than 1%.

The thirty-three coagulants tested consisted of eight anionic polymers, 23 cationic polymers, and alum and lime. The average percent removal of turbidity and suspended solids for the anionic polymers and the cationic polymers are listed in Table 19. The percent removal for alum and lime for the waters tested are listed in Table 20.

From these preliminary laboratory tests, a group of seven coagulants was chosen to be used in the bench-scale treatability tests. These seven were chosen based upon their turbidity and suspended solids removal ability. This group includes the coagulants listed in Table 21.

TABLE 19. ANIONIC AND CATIONIC COAGULANT REMOVAL SUMMARY

	Anionic percent removal		Cationic percent removal	
	turb	tss	turb	tss
PA-1	70.7	86.4	66.5	70.1
WV-1	56.5	33.5	79.7	49.1
WV-2	53.0	53.5	29.9	67.5
WV-3	78.5	58.4	83.7	65.7
WV-4	84.1	87.4	90.4	94.3
KY-1	78	70.8	76.1	72.4

TABLE 20. TURBIDITY AND SUSPENDED SOLIDS REMOVAL FOR ALUM AND LIME

	Alum percent removal		Lime percent removal	
Test water	turb	tss	turb	tss
PA-1	0	0	0	0
WV-1	0	0	16	0
WV-4	86	85	96	94
KY-1	80	65	84	60

TABLE 21. SELECTED COAGULANTS FOR BENCH SCALE TESTING

	Avg. % removal	
Code #	turb	tss
6E	71.2	80.5
17H	76.3	75.8
31A	75.3	74.8
44B	77.7	73.8
46A	78.3	85.1
46D	71.2	67.0
315	82.5	76.0

Step Three - Bench-Scale Treatability Study--

The purpose of step-three testing was to determine the optimum dosage of each of the seven coagulants for maximum turbidity and suspended solids removal. The first series of tests to determine the optimum dosage was performed at 21° C. After determining the optimum dosage at this temperature, the test was performed again; however, this time at 4° C to simulate winter conditions to observe the effect of temperature on the coagulation efficiency.

The laboratory procedure for these tests was identical to that described for step two testing. The results of the testing for step three are listed by dosage in Table A-4 and the percent removal at optimum dosage are listed in Table A-5. A summary of the average percent removals of turbidity and suspended solids for each coagulant is as follows:

TABLE 22. COAGULANT EFFICIENCY

Coagulant	Avg. % removal turb	tss
Magnifloc 587C	81.1	88.0
M-502	78.9	83.4
Amerifloc 485	78.5	77.5
Hercofloc 812	82.7	90.3
Hercofloc 831	74.6	75.7
Polyfloc C	81.8	87.8
Superfloc 315	75.6	78.9

An additional important aspect of coagulant usage is the dosage required to attain the maximum removal. Table 23 lists the average optimum dosage required for each coagulant, as determined in the bench-scale testing.

TABLE 23. AVERAGE OPTIMUM DOSAGE (mg/l)

Coagulant	Turb removal	Tss removal
Magnifloc 587C	3.6	3.5
M-502	3.3	3.6
Amerfloc 485	3.25	3.0
Hercofloc 812	3.8	2.9
Hercofloc 831	2.4	2.2
Polyfloc C	3.1	4.0
Superfloc 315	4.8	4.0

The following overall conclusions were reached as a result of the bench-scale testing:

- Cationic polymers were generally more effective than the anionic polymer.

- Magnifloc 587C performed efficient suspended solids removal of all test waters both at room temperature and at 4° C.

- M-502 performed efficient suspended solids removal of all test waters both at room temperature and at 4° C.

- Amerfloc 485 reduced the suspended solids of every water below discharge limitations except WV-3 at 4° C. A significant increase in suspended solids concentration was observed for WV-1 and WV-3 at 4 C using the 21° C optimum dosage.

- Hercofloc 812 sufficiently removed the suspended solids from all waters at 21° C, but did not meet discharge limitations at 4° C for WV-1, WV-3, and KY-1 using comparable dosages. Suspended solids concentration increased at 4° C for all waters other than WV-4.

- Hercofloc 831 sufficiently removed the suspended solids at 21° C for all waters except WV-4 and KY-1.

- Superfloc 315 sufficiently removed the suspended solids from all waters at 21° C, but did not meet discharge limitations at 4° C for WV-1, using the same dosage. Suspended solids concentration increased at 4° C for all waters.

- Polyfloc C exhibited less suspended solids removal efficiency at 4° C and did not meet discharge limitations for WV-1, WV-2, WV-4, and KY-1 at the lower temperature.

- Optimum coagulant dosage varies with characteristics of the subject water.

- Coagulant dosage will generally increase with the colloidal suspended solids concentration.

- Sludge generated during coagulation will be a function of the amount of solids in the water; however, under laboratory conditions, a significant amount of sludge could not be produced to obtain any data to characterize coagulants.

- Table 24 indicates the effect of water temperature and suspended solids removal of the control and two best performing coagulants.

TABLE 24. EFFLUENT SUSPENDED SOLIDS AT CONTROLLED TEMPERATURES

Water	Polymer	Dosage (mg/l)	Suspended solids (mg/l) @ 21°C	Suspended solids (mg/l) @ 4°C
PA-1	Control	--	32	65
	Magnifloc 587C	0.5	1	7
	M-502	1.0	1	11
WV-1	Control	--	29	64
	Magnifloc 587C	1.0	17	20
	M-502	3.0	7	29
WV-2	Control	--	28	10
	Magnifloc 587C	1.0	7	7
	M-502	0.5	5	8
WV-3	Control	--	74	101
	Magnifloc 587C	5.0	14	12
	M-502	3.0	27	13
WV-4	Control	--	1176	962
	Magnifloc 587C	6.0	12	3
	M-502	6.0	11	16
KY-1	Control	--	186	70
	Magnifloc 587C	6.0	12	18
	M-502	8.0	21	20

As a result of the preliminary and bench-scale treatability study, the following is a list of the seven tested coagulants in order of their overall performance:

1. Magnifloc 587C
2. M-502
3. Amerfloc 485
4. Hercofloc 812
5. Superfloc 315
6. Polyfloc C
7. Hercofloc 831

Step Four - Potential Environmental Impacts of Coagulant Use--

For each of the cationic coagulants used in the bench-scale testing, two potential sources of environmental impacts were studied. These were the supernatant or effluent of a pond in which the coagulants were used, and the sludge generated from the flocculation and settling of the suspended matter in the pond.

Information relative to the environmental impacts of the coagulants mentioned above were concentrated on the highest dosages recommended for each polymer in this study; however, potential effects of at least one coagulant were studied for each of the six mine waters whether or not that particular coagulant was required in the highest concentration.

The primary sources of information for the sludge related environmental impacts were published information and data from various coagulant producers, and phone conversations with producers' research and development personnel. In addition to these sources, pond overflow impact data was extracted from analytical testing of the clarified mine waters obtained from the bench scale evaluations of optimum coagulant dosages.

Coagulants and Mine Waters Studied--As stated previously, the environmental impacts of six separate cationic coagulants were studied with respect to their maximum optimum dosage on six separate mine waters. Specific environmental impact data was analyzed for the following systems: (1) 3.0 mg/l of M-502 added to mine water WV-1; (2) 3.0 mg/l of Superfloc 315 added to mine water WV-2; (3) 7.0 mg/l of Hercofloc 812 added to mine water WV-3; (4) 10.0 mg/l of Superfloc 315 added to mine water WV-3; (5) 6.0 mg/l of Amerfloc 485 added to mine water WV-4; (6) 6.0 mg/l of Magnifloc 587 C added to mine water WV-4; (7) 1.5 mg/l of Polyfloc C added to mine water PA-1; (8) 6.0 mg/l of Polyfloc C added to mine water KY-1; and (9) 8.0 mg/l of M-502 added to mine water KY-1.

General Toxicity and Stability Characteristics--

Of the six cationic polymers listed in this section, four are in liquid form and two are in solid form. The two solid polymers are Polyfloc C and Hercofloc 812. All of these are completely soluble in water and all are stable within the pH ranges of 3.5 to 8.0. It should be noted that all mine waters tested in this study were within the pH range of 5.6 to 7.4, and therefore no polymer stability problems were encountered. Three of the four liquid polymers, Amerfloc 485, M-502 and Magnifloc 587C, will freeze at -5° C in the concentrated form and therefore their use may be limited in cold weather areas unless a heated building or other facility is provided.

While most of these polymers exhibit a BOD of about 100,000 mg/l and COD of about 200,000 mg/l in the concentrated form, they are normally added in such small concentrations (less than 10.0 mg/l) that their effect on BOD or COD in the total mine water system is negligible. In addition, these materials exhibit very low toxicity characteristics. For instance, the lethal dosage of M-502 on white rats is 16.0 grams per kilogram of animal weight when injected directly into the stomach. This is approximately 10% of the toxicity of a concentrated salt solution injected into the same animal.

With the exception of Polyfloc C for which no information could be found, all polymers studied have received EPA approval for usage in potable water. However, the EPA dosage limit for approval of Hercofloc 812 was exceeded in the findings for optimum coagulant dosage.

Environmental Impact of Sludge Containing Polymer--

In the coagulant/mine water systems which were studied, the majority of the various polymers injected in the laboratory-scale treatment tests became adhered to floc particles and thus settled out with the sludge. These polymers remain in a stable condition in this sludge as long as it remains untouched in the bottom of the settling basin.

Since polymers are all extremely long chained organic molecules, the introduction of any sludge removing device into the system will shear these molecules, thus causing a significant degree of instability. With the proper care and initiation of good sludge disposal practices, the impact of this phenomenon on the environment can be minimal. For instance, if a settling pond is full of sludge, the top layer of water should be pumped off and no discharge be allowed from the pond while the sludge is being pumped out and hauled away. This may require the re-routing of the normal influent stream into another settling basin until the sludge removal operation is completed.

If only one settling pond exists, it should be baffled so that sludge cannot accumulate on the effluent end of the pond. That way, when the influent side of the pond becomes filled with sludge, the influent water stream can be repiped to the other section temporarily while the sludge from the first section is pumped out. The baffle should be located one third of the distance from the inlet to the outlet.

Even if these sludges would break down and return to the suspended solids form during pond cleanout periods, the suspended solids concentration in the lagoon effluent should not be higher than if no coagulant was added to the system at all unless the pond had been completely overrun by sludge before an attempt was made to pump it out. In that case, lack of retention time in the pond would result in high suspended solids concentrations in the effluent no matter how well the polymer aided settling time.

One final comment is that all five coagulant producers stressed that their polymer, if broken down by strong shearing action, would not form smaller toxic type molecules that could harm the environment in any way.

Environmental Impact of Polymer in Pond Overflows--

Each of the six cationic polymers mentioned previously are completely soluble in water. Therefore, whatever amount of the polymer that does not attach itself to the floc will be present in the pond overflow as dissolved solids, COD, or soluble organic carbon. Normally, this represents less than 10% of the total coagulant dosage added to the mine water stream, therefore it is usually not too significant a quantity.

To determine what impact polymer addition has on the analyses of certain pond effluents without knowing the exact chemical structure of each coagulant is most difficult; however, to obtain some type of specific environmental impact data for the coagulant systems discussed under the sub-title "Bench-Scale Treatability Test", the study began by dosing deionized water with the same concentrations of polymers as indicated in these tests. The deionized water containing the polymers was analyzed for total dissolved solids (TDS), total organic carbon (TOC), and chemical oxygen demand (COD). The results were as follows:

Coagulant	Dosage (mg/l)	TDS (mg/l)	TOC (mg/l)	COD (mg/l)
M-502	8.0	1	6.4	1
Superfloc 315	10.0	36	5.4	8.0
Hercofloc 812	7.0	18	6.1	8.0
Magnifloc 587C	6.0	72	9.8	1
Amerfloc 485	6.0	1	5.8	1
Polyfloc C	6.0	22	5.8	8.0

These results indicate that M-502 and Amerfloc 485 do not add dissolved solids to the water, and that M-502, Amerfloc 485, and Magnifloc 587C do not add COD to the water. Since there are at most 2.0 mg/l of TOC in this deionized water, all polymers contributed in that respect.

Next, the supernatant samples produced from the optimum polymer dosages were compared to the effluents of each mine water without polymer added (control samples), with respect to dissolved solids, suspended solids and TOC. The results are summarized below.

System #1: 3.0 mg/l of M-502 added to WV-1

	Effluent Analysis Control	Effluent Analysis With Polymer
TSS (mg/l)	29	7
TDS (mg/l)	670	606
TOC (mg/l)	6.2	7.8

Conclusion: Calgon M-502 added a slight amount of non-toxic organics to the WV-1 pond effluent stream, but more than compensated for this removal of most of the suspended solids.

System #2: 3.0 mg/l of Superfloc 315 added to WV-2

	Effluent Analysis Control	Effluent Analysis With Polymer
TSS (mg/l)	28	14
TDS (mg/l)	48	96
TOC (mg/l)	6.1	8.3

Conclusion: American Cyanamid Superfloc 315 added 2.0 mg/l of non-toxic organics to the WV-2 pond effluent, and also added some dissolved solids, but again reduced the suspended solids to one half of that obtained without the use of this polymer.

System #3: 7.0 mg/l of Hercofloc 812 added to WV-3

	Effluent Analysis Control	Effluent Analysis With Polymer
TSS (mg/l)	74	4
TDS (mg/l)	332	374
TOC (mg/l)	11	11

Conclusion: Hercules Hercofloc 812 added dissolved solids to the WV-3 pond overflow; however, the sharp drop in suspended solids makes the effluent more environmentally aesthetic. Probably a tradeoff of organics with more natural organics precipitating out while Hercofloc 812 added some to the overflow.

System #4: 10.0 mg/l of Superfloc 315 added to WV-3

	Effluent Analysis	
	Control	With Polymer
TSS (mg/l)	74	12
TDS (mg/l)	332	376
TOC (mg/l)	11	4.7

Conclusion: Same as System #3 except that American Cyanamid Superfloc 315 pulled down a considerable amount of natural organics into the sludge.

System #5: 6.0 mg/l of Amerfloc 485 added to WV-4

	Effluent Analysis	
	Control	With Polymer
TSS (mg/l)	1176	10
TDS (mg/l)	236	164
TOC (mg/l)	26	8.5

Conclusion: Drew Amerfloc 485 caused a tremendous improvement in each case with respect to the environmental impact of the pond overflow.

System #6: 6.0 mg/l of Magnifloc 587C added to WV-4

	Effluent Analysis	
	Control	With Polymer
TSS (mg/l)	1176	12
TDS (mg/l)	236	146
TOC (mg/l)	26	11

System #7: 1.5 mg/l of Polyfloc C added to PA-1

	Effluent Analysis	
	Control	With Polymer
TSS (mg/l)	32	6
TDS (mg/l)	392	364
TOC (mg/l)	5.9	4.3

System #8: 6.0 mg/l of Polyfloc C added to KY-1

	Effluent Analysis	
	Control	With Polymer
TSS (mg/l)	186	14
TDS (mg/l)	264	238
TOC (mg/l)	12	11

Conclusions for systems 5, 6, 7, and 8 are similar.

System #9: 8.9 mg/l of M-502 added to KY-1

	Effluent Analysis	
	Control	With Polymer
TSS (mg/l)	186	21
TDS (mg/l)	264	248
TOC (mg/l)	12	15

Conclusion: Calgon M-502 added 3.0 mg/l of TOC to the pond overflow for KY-1 with very little effect on environmental impact for this small amount of non-toxic organics.

Summary--

One must realize that the true environmental impact can not be measured from laboratory data. A field analysis of impact on an actual ecosystem must be performed to conclusively indicate the impact of coagulant usage. Preliminary indications are, however, that environmental impact, if any, will be slight.

The Application of Coagulant Usage in Suspended Solids Removal

In order to make a decision regarding the usage of coagulants to assist in the removal of suspended solids, several items must be considered including a laboratory treatability analysis to determine coagulant optimum dosage, an economic analysis to determine feasibility of coagulant treatment, and an engineering design of the method of applying the coagulant to the pond.

Laboratory Treatability Analysis--

A laboratory analysis of a sample of water to be treated is an integral part of the design process. Several basic steps are required:

1. A coagulant screening process must be performed to determine the most applicable products. The list of thirty-three coagulants previously used for the preliminary study may be consulted in conducting this review. Results have shown that a cationic liquid coagulant will give desirable results and may be used as a basis for elimination.

2. A preliminary laboratory analysis should be performed to determine the range of applicability of each coagulant chosen during step one screening. The laboratory procedure described in the previous section may be utilized for this preliminary analysis.

3. After determining a group of the most successful coagulants, during preliminary testing, a bench-scale treatability study should be performed to determine the dosage at which maximum suspended solids removal will occur. This can be performed by using the same laboratory procedure as described in step two with a variation of dosages. The data from this step should be plotted on graph paper to display the relationship between percent removal and coagulant dosage. From this graph, the desired dosage of coagulant may be picked depending upon the amount of suspended solids removal required to comply with the effluent limitations.

4. As a final laboratory test, a study should be performed to determine the effect of cold weather on coagulant effectiveness by simulating winter conditions in the laboratory. This can be accomplished by using a cold water bath to maintain low temperatures in the reaction vessels.

After final laboratory analysis is complete, a complete report of the findings should be compiled along with recommendations generated during the study.

Economic Feasibility--

The second phase of coagulant review entails the economic feasibility of treatment. Detailed cost data should be obtained from the manufacturer of the selected coagulants. After receiving this data, a cost comparison should be performed on a unit basis of flow rate. For example, Table 25 is a summary cost comparison of the seven coagulants tested in the previous laboratory bench-scale treatability study. Table 25 was generated by computing the amount of required coagulant for a flow rate of .0283m^3/sec (1 CFS). It is interesting to observe that the two most effective coagulants were also the least expensive. The economic feasibility analysis should also be done to determine the costs associated with the hardware of the coagulant addition system.

Engineering Design of Coagulant Addition Systems--

As was previously detailed in the section discussing the theory of suspended solids removal, the process of coagulation consists of two separate phases: 1) chemical addition with rapid mixing and 2) flocculation during which a very slow mix of the treated water takes place to allow for particle aggregation. The method of chemical addition depends upon the nature of the coagulant; i.e., whether it is a solid powder or a liquid.

TABLE 25. COST OF COAGULANT USAGE

Coagulant	Unit cost	Dosage (mg/l)	Cost/day
Magnifloc 587C	$ .34/lb.	3.5	$ 6.42
M-502	$ .45/lb.	3.6	$ 8.74
Amerfloc 485	$1.00/lb.	3.0	$16.18
Hercofloc 812	$2.60/lb.	2.9	$40.68
Hercofloc 831	$2.40/lb.	2.2	$28.48
Polyfloc C	$1.45/lb.	4.0	$31.29
Superfloc	$ .48/lb.	4.0	$10.36

If a solid coagulant is used, a stock solution must be prepared as an initial step. A typical system for makeup and metering of a coagulant solution utilizes a platform scale (0 - 60 lbs minimum), with the container of powder attached to a 1890 liter (500 gal) make-up tank by a vacuum hose, through which the powder is fed. This stock solution is usually prepared at a concentration from 0.25 - 0.5% by weight with clean water at near normal pH. An increased temperature will help facilitate the dissolution of the powder, but should never exceed 40.5° C (105° F). Water is added to the make-up tank and a mixer (3/4 hp) agitates the solution for about 30 minutes. This mixture is then pumped to a 3790 liter (1000 gal) holding tank.

Actual addition of the solid coagulant stock solution should be controlled by a metering pump to ensure proper dosage. A variable speed, corrosion resistant, positive displacement pump is recommended. Prior to addition to the waste stream, a second dilution (10:1) should take place. This can be accomplished with a dilution tee immediately after the pump. A length of pipe sufficient to facilitate mixture (100-pipe diameters) should be used between the tee and the point of addition. All equipment should be stainless steel, fiberglass, or plastic wherever possible to avoid clogging and/or corrosion. Care must be taken to maintain clean fixtures.

For the addition of a liquid product, a transfer pump, mixing tank, and equipment for final dilution are used. This process may be operated manually or automatically, depending on whether suitable controls are installed. Since most surface mine sedimentation ponds are located in relatively remote areas, the manual method of addition is recommended. A batch solution of liquid coagulant is prepared in the mixing tank at a 0.25 - 0.5% concentration. if electricity and a water supply is available at the site, then a system identical to the powder stock solution addition system, using a metering pump and dilution tee, should be used. If no electricity is available, a gravity feed system should be designed whereby a preset volume of diluted coagulant solution is allowed to drain from the batch-mix tank.

The actual metering of the coagulant solution to the stream may be accomplished by a combination of flow sensing device and variable speed metering pump. A device such as a parshall flume with level sensor should be designed to control the variable speed pump thereby delivering the correct dosage to the waste stream. In the event of a remote installation, an arrangement would be satisfactory in which a float-actuated valve, with the float located in the measuring flume, would control the amount of coagulant flowing from a gravity feed system.

When designing a sedimentation basin with a coagulant addition system, an allowance must be made for preliminary settling of large size particles. This can be accomplished by series settling ponds as described in the physical modifications section of this report. If preliminary sedimentation is not used, the larger particles may interfere with the coagulant and require chemical addition in excess of that amount actually required to settle the small particles. In the suspended solids removal process, the coagulant addition system should be located after the preliminary sedimentation basin.

After the addition of the coagulant, the water-coagulant mixture must go through a short phase of violent rapid mixture followed by a period of slow mix settling. As stated previously, because of the remote location of surface mine sedimentation ponds, these rapid mix and slow mix processes must be designed using non-mechanical techniques. If sufficient head is available, a waterfall step-method of rapid mixing is possible. By taking advantage of the natural fall in the stream channel, a series of steps constructed of rock or logs, causing a cascade effect from one step to the other, may be used to cause violent agitation of the treated stream. If sufficient head is not naturally avaiable, an artificial head could be made available by construction techniques.

The period of rapid mix should be followed by a period of flocculation during which the particles in solution are mixed very slowiy to allow particle contact and aggregation. This phase must be designed to minimize turbulence as the flocculated particles can be fragile and susceptible to resuspension if disburbed. The actual flocculation process will take place in the final sedimentation basin with the slow mixing occurring in the first one-half of the basin. Baffles should be placed in the head end of the pond to cause the flow to be directed in a snake-like fashion as depicted in Figure 46. The final baffle should be placed so as to outlet the flow in the central portion of the pond. The remaining two-thirds of the basin would then be utilized for quiescent settling of the flocculated material. Extreme care must be taken in the design of outlet facilities so as to minimize turbulence and carry-over of the floc.

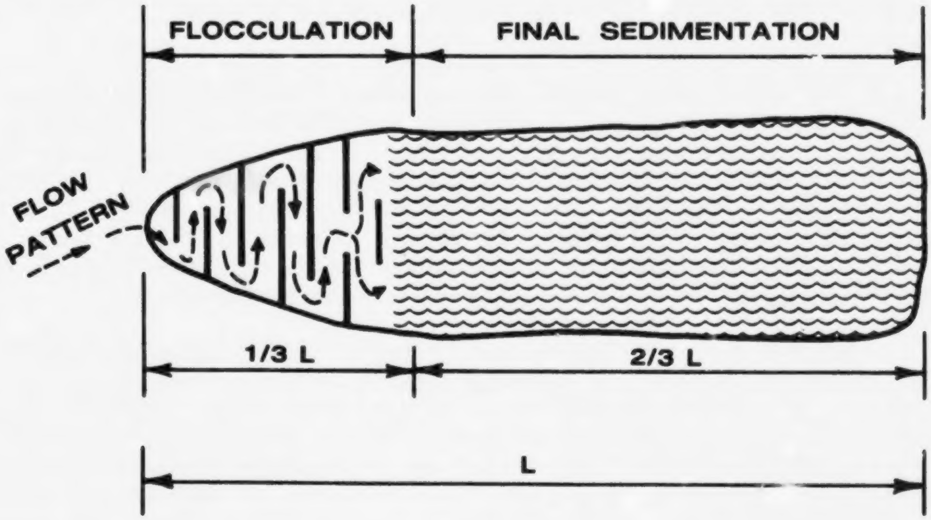


Figure 46. Flocculation by baffle placement.

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TABLE A-1. COAGULANT MANUFACTURER SURVEY

MANUFACTURER	TRADE NAME
ABCO Pool Industries 151 - 23 34th Avenue Flushing, N. Y. 11352 (212) 463 - 2100	
Alken - Murray Corp. 109 - 111 Fifth Avenue N. Y., N. Y. 10029 (212) 777 - 6560	
Allied Colloids, Inc. One Robinson Lane Ridgewood, N. J. 07450 (201) 447 - 4121	Percol 877 Percol 352 Percol 455 Percol 511 Percol 1011 Percol 351 Percol E 24 Percol 155 Percol 156 Percol 720 Percol 725 Percol 726 Percol 727 Percol 730 Percol 722 Percol 728 Percol 763 Percol 757 Percol 776 Percol 744 Percol 751 Percol 788 N
Allstate Chemical Co. Box 3040 Euclid, Ohio 44117 (216) 382 - 3900	

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
American Colloid Co. 5100 Suffield Court Skokie, Ill. 60076 (312) 966 - 5720	Accofloc 361 Accofloc 352 Accofloc 350
American Cyanamid Water Treating Chemical Dept. Berdan Avenue Wayne, N. J. 07470 (201) 831 - 1234	Magnifloc 573 C Magnifloc 577 C Magnifloc 581 C Magnifloc 585 C Magnifloc 589 C Magnifloc 1986 N Magnifloc 1849 A Magnifloc 587 C
Armour Industrial Chemical Co. P. O. Box 1805 Chicago, Ill. 60690 (312) 242 - 2750	Arquad 2c/75 Arquad 2HT/75 Arquad T2C/50 Ethoquad /12
Arnold & Clark Chemical Houston, Texas 77001 (713) 869 - 0541	
Baroid Division Box 1175 Houston, Texas 77001 (713) 527 - 1500	Barochem AF452 Barochem AF454 Surflo A100 Surflo A116 Surflo A117 Surflo A119 Barafloc 800 Barafloc 802 Barafloc 804 Barafloc 806 Barafloc 808 Barafloc 810
Berdell Industries 28 - 01 Thomson Avenue Long Island City, N. Y. 11101 (212) 361 - 7660	

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Betz Laboratories, Inc. 4636 Somerton Road Trevose, Pa. 19047 (215) 355 - 3300	
Bond Chemicals, Inc. 1500 Brookpark Road Cleveland, Ohio 44109 (216) 741 - 6935	
Borden Chemical 50 West Broad Street Columbus, Ohio 43215 (614) 225 - 4000	C77-120 C121-21 B PR-450 PR-338 C163-86 C138-79 C163-86 + C138-79
Brenco Corp. 704 North First Street St. Louis, Mo. 63102 (314) 621 - 8457	
Buckman Laboratories, Inc. 1256 North McLean Blvd. Memphis, Tenn. 38108 (901) 278 - 0330	HCAT-1 HMWCP WSCP-2 WSCP NONI4 ANNI1
C. E. Minerals Division of Combustion 901 East 8 Avenue King of Prussia, Pa. 19406 (215) 265 - 6880	
Calgon Corp. Water Chemical Dept. P.O. Box 1346 Pittsburgh, Pa. 15222 (412) 923 - 2345	CATFLOC CATFLOC T CATFLOC T1 CATFLOC 21 CATFLOC 121

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Calgon Corp. (continued)	CATFLOC B CATFLOC S M-502 CA-233 CA-243 CA-253 WT-2640 M-540 L-650 E L-670 E L-690 E L-670 L-690 M-570 M-580 M-590
Carborundum Co. Water Mgmt. Div. Niagara Falls, N. Y. 14302 (716) 278 - 2572	
Carus Chemical Co., Inc. 1500 Eighth Street LaSalle, Ill. 61301 (815) 223 - 1500	91-AP 95-AP
Celanese Polymer Specialties Co. Stein Hall & Co. Technical Center 9800 East Bluegrass Pkwy. P. O. Box 99038 Jeffersontown, Ky. 40299 (502) 585 - 8101	Polyhall 295 Polyhall 295 C Polyhall 1320 Polyhall 1650 Polyhall 1430 Polyhall 1082 Polyhall 522 D Jaguor C-13

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Chromalloy American Corp. 641 Lexington Avenue N. Y., N. Y. 10001 (212) 838 - 1177	
Cities Service P. O. Box 50360 Atlanta, Ga. 30302 (404) 261 - 9100	Ferri-Floc
Commercial Chemical Products, Inc. 11 Patterson Avenue Upper Saddle River, N. J. 07432 (201) 444 - 9100	
Crown Zellerbach Corp. Chemical Div. Camas, Washington 98607 (206) 834 - 4444	Orzan A Orzan S
Crusader Chemical Co., Inc. 2330 Severn Baltimore, Md. 21230 (301) 752 - 7602	
Cutter Laboratories, Inc. Fourth & Parker Street Berkley, Cal. 94701 (415) 841 - 0123	
Dade Div. 1851 Del. Pky. P. O. Box 52067 Miami, Fla. 33101 (305) 633 - 6461	

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Dearborn Chemical Co. Div. W. R. Grace & Co. Merchandise Mart Plaza Chicago, Ill. 60654 (312) 438 - 8241	
Diamond Shamrock Corp. 1415 East Marlton Pike Route 70 Cherryhill, N. J. 08034 (609) 428 - 7035	Silica Sols
Dow Chemical Co. P. O. Box 1847 2040 Dow Center Midland, Michigan 48640 (517) 636 - 6053	Separan MA-200 Separan MA-700 EPXD 30150 EPXD 30204
Drew Chemical Corp. One Drew Chemical Plaza Boonton, N. J. 07005 (201) 263 - 7822	Amerfloc 485 Amerfloc 2265 Drewfloc 495 Drewfloc 2306 Drewfloc 2270
Dubois Chemicals Div. of W. R. Grace & Co. Dubois Tower Cincinnati, Ohio 45202 (513) 769 - 4200	
E. I. DuPont De Nemours & Co. Wilmington, Del. 19898 (302) 774 - 1000	Ferric Chloride
Electro - Chemical & Engineering Emmaus, Pa. 18049 (215) 965 - 9061	

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Exxon Chemicals Box 222, Building 12 Room 312 A Linden, N. J. 07036 (201) 474 - 7499	
Fabcon International 1275 Columbus Avenue San Francisco, Cal. 94133 (415) 928 - 2400	
Facet Enterprises Newark, Del. 19711 (302) 731 - 4689	
Henry W. Fink & Co. 6900 Silverton Avenue Cincinnati, Ohio 45235 (513) 891 - 5583	100 Kleer-Floc 102 Kleer-Floc 107 Kleer-Floc 108 Kleer-Floc 110 Kleer-Floc 116 Kleer-Floc 453 Kleer-Floc
G. A. F. Corporation 140 West 51st Street N. Y., N. Y. 10020 (212) 582 - 7600	
Gamlen Chemical Elwood, N. J. 08217 Bergen County (609) 894 - 9264	
General Mills Chemicals 4620 West 77th Street Minneapolis, Mn. 55435 (612) 830 - 7968	Galactasol 212 Galactasol SJM Gendrix Supercol Galactasol-813

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
A. F. Gooman and Sons 21 - 07 41st Street Long Island City, N. Y. 11101 (212) 392 - 8400	
B. F. Goodrich Chemical Co. 6100 Oak Tree Blvd. Cleveland, Ohio 44131 (216) 524 - 0200	
Haviland Product Co. 421 Ann Street, N. W. Grand Rapids, Mi. 49504 (616) 361 - 6691	Polyfloc A Polyfloc C Ployfloc MP
Heede International Stamford, Conn. 06904 (203) 327 - 3320	
Hercules Inc. 910 Market Street Wilmington, Del. 19899 (302) 995 - 3860	Herofloc 812 Herofloc 818 Herofloc 821 Herofloc 831 Herofloc 849 Herofloc 874
Franz Herzel 150 East 58th Street N. Y., N. Y. 10017 (212) 421 - 7060	
Hodag Chemical Corp. 7247 North Central Avenue Skokie, Ill. 60076 (312) 675 - 3950	

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Hyland Laboratories 3300 Hyland Avenue Costa Mesa, Cal. 92626 (714) 540 - 5000	
ICI Americans Wilmington, Del. 19899 (302) 575 - 3518	
Illinois Water Treatment Co. 4669 Shepherd Trail Rockford, Ill. 61105 (815) 877 - 3041	IFA-313
KSH Chemicals Corp. 313 Cox Street Roselle, N. J. 07068 (201) 245 - 8800	
Kelco Co. 75 Terminal Avenue Clark, N. J. 07066 (201) 381 - 6900	
Key Chemicals, Inc. 4346 Tacony Street Philadelphia, Pa. 19124 (215) 744 - 5858	
Klenzoid Equipment Co. 912 - T Avenue Conshohocken, Pa. 19428 (215) 825 - 9494	
F. B. Leopold Co. Zelienople, Pa. 16063 (412) 452 - 6300	

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Magna Corp. Tech. Services Div. Houston, Texas 77001 (713) 795 - 4270	
Miles Laboratories, Inc. 1127 Myrtle Street Elkhart, Ind. 46514 (800) 356 - 9393	
Moqul Corp. 20600 Chagrin Blvd. Cleveland, Ohio 44122 (216) 248 - 6914	
Monsanto Company 800 N. Lindbergh Blvd. St. Louis, Mo. 63141 (314) 694 - 1000	
Nalco Chemical Co. 2901 Butterfield Rd. Oak Brook, Ill. 60521 (312) 887-7500	
National Starch & Chemical Corp. 1700 West Front St. Plainfield, N.J. 07063 (201) 685 - 5000	
Oakite Products, Inc. 50 Valley Road Berkeley Hts., N.J. 07922 (201) 464 - 6900	
O'Brien Industries, Inc. 513 W. Mt. Pleasant Ave. Livingston, N.J. 07039 (201) 992 - 0660	

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Oxford Chemical Division Consolidated Foods, Corp. P.O. Box 80202 Atlanta, Ga. 30341 (404) 452 - 1100	
Permutit Co. 49 East Midland Ave. Paramus, N.J. 07652 (201) 262 - 8900	
Peter Cooper Corp. Palmer St. Gowanda, N.Y. 14070 (716) 532 - 3344	
Petrolite Corp. 369 Marshall St. St. Louis, Mo. 63119 (314) 961 - 3500	
Philadelphia Quartz Co. P.O. Box Valley Forge, Pa. 19481 (215) 293 - 7200	
Reichhold Chemicals 523 North Broadway White Plains, N.Y. 10602 (914) 682 - 5700	
Rohm & Haas Co. Independence Mall West Philadelphia, Pa. 19105 (215) 592 - 3000	Primafloc C-3 Primafloc C-7 Primafloc A-10
A. E. Staley, MFG Co. P.O. Box 151 Decatur, Ill. 62525 (217) 423 - 4411	Hamaco 196 Gum Potato Starch

(continued)

TABLE A-1. (continued)

MANUFACTURER	TRADE NAME
Standard Brands Chemicals 625 Madison Avenue N.Y., N.Y. 10022 (212) 759 - 4400	
Techni-Chem. East State Street Box 428 T Cherry Valley, Ill. 61016 (815) 332 - 4987	
Union Carbide Corp. 270 Park Avenue N.Y., N.Y. 10017 (212) 551 - 2345	Polyox WSR-301 Polyox WSR Coag
Unitech Chemical, Inc. Swift Products 115 West Jackson Blvd. Chicago, Ill. 60604 (312) 431 - 3560	X-100 X-400 X-420 X-110 X-700
Val - Chem. Corp. P.O. Box 172 Edison, N. J. 08817 (201) 985 - 3773	
James Varley & Sons 1200 Switzer Avenue St. Louis, Mo. 63147 (314) 383 - 4372	
Witco Chem. Corp. 227 A. Park Avenue N.Y., N.Y. 10001 (212) 644 - 6300	
Zimmite Corp. 810 Sharon Drive Westlake, Ohio 44145 (216) 871 - 9660	

TABLE A-2. COAGULANT/FLOCCULANT DATA FORM

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME		
		Percol 727	Magnifloc 573C	Magnifloc 577C
	CODE	3-M	6-A	6-B
CHEMICAL	**Composition**	Polyelectrolyte	Polyelectrolyte	Polyelectrolyte
	Ionic Charge	Anionic (Medium to High)	Cationic	(High) Cationic
PHYSICAL	**Reagent Form**	(Granular) Powder	Liquid	Liquid
	Molecular Weight	Ultra-High		High
	Freezing Point		0° F (Can be used after it freezes)	0° F (Can be used after it freezes)
SOLUTION PREPARATION	**Dilution**	Stock: 0.10% - 0.25%	100:1	100:1
	Mixing Time	Handshake 10-15 Sec., Occasional Shaking 30-60 Min.	20 - 30 Minutes	20 - 30 Minutes
	Shelf Life	Solid: Up to 2 Years Stock Solution: Up to 5 Days	12 - 14 Months	50° - 100° F: 12 Months
STORAGE	**Reagent**	Cool, Dry Place	Store in Glass, Stainless Steel, Plastic or epoxy-lined vessels	Store in Glass, Stainless Steel, Plastic or epoxy-lined vessels
	Stock Solution	Dark Place		
	TYPICAL APPLICATIONS	Waste Treatment, primarily for settling application either by itself or with inorganic primary coagulants	Gravity settling; clarification; settling basins	De-watering sludge; settling and clarifying

(continued)

TABLE A-2. (continued)

COAGULANT CHARACTERISTICS		REAGENT TRADE NAME Magnifloc 581C	 Magnifloc 585C	 Magnifloc 587C
CODE		6-C	6-D	6-E
CHEMICAL	**Composition**	Polyelectrolyte	Polyelectrolyte	Polyelectrolyte
	Ionic Charge	(High) Cationic	Cationic	(High) Cationic
PHYSICAL	**Reagent Form**	Liquid	Liquid	Liquid
	Molecular Weight .	High	Low	Low
	Freezing Point	0° F (Can be used after it freezes)	-5° C (Can be used after freezing)	-5° C (Can be used after freezing)
SOLUTION PREPARATION	**Dilution**	100:1	100:1	100:1
	Mixing Time	20 - 30 Minutes	20 - 30 Minutes	20 - 30 Minutes
	Shelf Life	12 - 14 Months	12 - 14 Months	12 - 24 Months
STORAGE	**Reagent**	Store in Glass, Stainless Steel, Plastic or Epoxy-lined vessels	Store in Glass, Stainless Steel, Plastic or Epoxy-lined vessels	Store in Glass, Stainless Steel Plastic or Epoxy-lined vessels
	Stock Solution			
TYPICAL APPLICATIONS		Gravity Settling; Clarification; Settling basins	Gravity Settling and other clarifiers	Particularly effective on low turbidity water

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME Magnifloc 589C	 Hicat 1	 Cat-Floc
	CODE	6-F	15-A	17-A
CHEMICAL	Composition	Polyelectrolyte	Polyelectrolyte (25% polymer solids)	Polyelectrolyte Polydimethyldiallyl NH_4 Cl
	Ionic Charge	Cationic	Cationic	Cationic
PHYSICAL	Reagent Form	Liquid	Liquid	Liquid
	Molecular Weight	High		
	Freezing Point	-5^{o} C (Can be used after freezing)		27^{o} F; Low temp. may cause feeding problems (viscosity)
SOLUTION PREPARATION	Dilution	100:1	Predilution 250:1 to make sol'n no > 0.1% polymer solids	$\geq$ 100:1
	Mixing Time	20 - 30 Minutes		Specially selected clay may be needed if time is short
	Shelf Life	12 - 24 Months		
STORAGE	Reagent	Store in Glass, Stainless Steel, Plastic or Epoxy-lined vessels		Heated Building
	Stock Solution			
	TYPICAL APPLICATIONS	Gravity Settling Operations; Mechanical dewatering	Clarify wastewater, sludge dewatering; mineral and chemical processing	Clarification

(continued)

TABLE A-2. (continued)

COAGULANT CHARACTERISTICS		REAGENT TRADE NAME		
		Cat-Floc T	Cat-Floc T-1	M-502
CODE		17-B	17-C	17-H
CHEMICAL	**Composition**	Polyelectrolyte Polydimethyldially NH_4 Cl	Polyelectrolyte Polydimethyldially NH_4 Cl	Polyelectrolyte Polydimethyldially NH_4 Cl
	Ionic Charge	Cationic	Cationic	Cationic
PHYSICAL	**Reagent Form**	Liquid	Liquid	(High viscosity) Liquid
	Molecular Weight			
	Freezing Point	27° F; Low temp. may cause feeding problems (viscosity), freezing may cause stratification	26° F; Low temp may cause feeding problems (viscosity)	27° F; Low temps may create feeding problems (viscosity)
SOLUTION PREPARATION	**Dilution**	≥100:1	≥100:1	≥100:1
	Mixing Time			
	Shelf Life			
STORAGE	**Reagent**	Heated Building	Heated Building	Heated Building
	Stock Solution			
TYPICAL APPLICATIONS		Clarification	Clarification	Mining industry clarification

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME		
		Ferri-Floc	Separan MG-200	Separan MG-700
	CODE	22-A	30-A	30-B
CHEMICAL	**Composition**	Ferric sulfate (Ferric hydroxide)	(Slightly hydrolyzed) Polyacrylamide	Polyacrylamide
	Ionic Charge	Cationic	(Slightly) Anionic	Anionic
PHYSICAL	**Reagent Form**	Dry powder	(Granular) Solid	(Granular) Solid
	Molecular Weight		Very high	Very high
	Freezing Point			
SOLUTION PREPARATION	**Dilution**		Maximum strength = 1% Usually ≤ 0.5%	Maximum strength = 0.5% Usually ≤ 0.5%
	Mixing Time	30 Minutes		
	Shelf Life	Reagent: 6-12 months Conc. Sol'n: recommend 60 days (but can store indefinitely)	Reagent: up to 2 years Stock sol'n: 1 month	Reagent: up to 2 years Stock sol'n: 1 month
STORAGE	**Reagent**	Slightly hygroscopic (avoid high humidity and no contact with water)	< 100° F and avoid high humidity	100° F and avoid high humidity
	Stock Solution		< 120° F	120° F
	TYPICAL APPLICATIONS	Turbidity removal; organic color removal; with lime softening; manganese removal; waste treatment; toxic metal removal.	Specific mining separation problems - for clarification sometimes used after alum or lime.	Mine water clarification; water treatment; coal prep. plants; tailings pond stabilization - for clarification often used after alum or lime.

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME		
		Experimental Polymer XD-30150.00	Experimental Polymer XD-30204	Amerfloc 485
	CODE	30-C	30-D	31-A
CHEMICAL	Composition	Polyacrylamide	Polyacrylamide	Organic Polyelectrolyte
	Ionic Charge	(Slightly) Anionic	(Moderately) Anionic	Cationic
PHYSICAL	Reagent Form	Powder	Powder	Liquid
	Molecular Weight	High	Very high	Moderate
	Freezing Point			32° F
SOLUTION PREPARATION	Dilution	Normally 0.5–1.0%	Normally 0.25–0.5%	5:1
	Mixing Time			
	Shelf Life	Stock sol'n: ≥0.25% = 1 month ≤0.05% = 1 day	Stock sol'n: ≥0.25% = 1 month ≤0.05% = 1 day	Reagent: 12 - 14 Months
STORAGE	Reagent	100° F and avoid high humidity	100° F and avoid high humidity	Store at 40° - 100° F
	Stock Solution	120° F	120° F	
	TYPICAL APPLICATIONS	Tailings water recovery; acid leaching; potash brine clarifying; preleach thickening.		Water and waste treatment; suspended solids; turbidity in wastewaters; heavy metals

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME Polyfloc C	 Hercofloc 812	 Hercofloc 818
	CODE	**44-B**	**46-A**	**46-B**
CHEMICAL	**Composition**	Synthetic Polyelectrolyte	Synthetic organic Polyelectrolyte	Synthetic organic Polyelectrolyte
	Ionic Charge	Cationic	(Low) Cationic	(Low) Anionic
PHYSICAL	**Reagent Form**	Liquid	Powder	Powder
	Molecular Weight	High	High	High
	Freezing Point	Should not permit freezing		
SOLUTION PREPARATION	**Dilution**	10-20:1	≤0.5%	≤0.5%
	Mixing Time		≥1 hour	≥1 hour
	Shelf Life		Reagent: 1 yr. (less if pH 6 of solution water) Sol'n: 1 week	Reagent: 1 year Sol'n: 1 week
STORAGE	**Reagent**		Dry, cool area	Dry, cool area
	Stock Solution			
	TYPICAL APPLICATIONS	Clarifying wastewater; settling suspended clays	Water and waste treatment	Water and waste treatment

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME		
		Hercofloc 821	**Hercofloc 831**	**Hercofloc 849**
	CODE	**46-C**	**46-D**	**46-E**
CHEMICAL	**Composition**	Synthetic organic Polyelectrolyte	Synthetic organic Polyelectrolyte	Synthetic organic Polyelectrolyte
	Ionic Charge	(High) Anionic	(Medium) Anionic	(Medium-High) Cationic
PHYSICAL	**Reagent Form**	Powder	Powder	Powder
	Molecular Weight	High	High	High
	Freezing Point			
SOLUTION PREPARATION	**Dilution**	≤0.5%	≤0.5%	≤0.5%
	Mixing Time	≥1 hour	≥1 hour	≥1 hour
	Shelf Life	Reagent: 1 year Sol'n: 1 week	Reagent: 1 year Sol'n: 1 week	Reagent: 1 yr. (less if pH 6 of sol'n water) Sol'n: 1 week
STORAGE	**Reagent**	Dry, cool area	Dry, cool area	Dry, cool area
	Stock Solution			
	TYPICAL APPLICATIONS	Water and waste treatment	Water and waste treatment	Water and waste treatment

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME Hercofloc 874	 Nalco 7107	 Nalco 7134
	CODE	**46-F**	**61-F**	**61-H**
CHEMICAL	**Composition**	Synthetic organic Polyelectrolyte		
	Ionic Charge	(Medium) Cationic	Cationic	Cationic
PHYSICAL	**Reagent Form**	Powder	Liquid	Liquid
	Molecular Weight	High	Low	High
	Freezing Point		After freeze, thaw and use; Freeze (conc.): 0° F	Avoid freezing due to viscosity; freeze (conc.): -15° F
SOLUTION PREPARATION	**Dilution**	≤0.5%		
	Mixing Time	≥1 hour		
	Shelf Life	Reagent: 1 yr. (less if pH 6 of sol'n water) Sol'n: 1 week	Reagent: 1 year 10% sol'n: 1 week	Reagent: 1 year Sol'n (≧ 10%): 1 week
STORAGE	**Reagent**	Dry, cool area		
	Stock Solution			
	TYPICAL APPLICATIONS	Water and waste treatment	Nonpotable water clarification and treatment systems.	Waste treatment clarification

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME Nalco 8851	 Nalco 8852	 Primafloc C-7
	CODE	61-K	61-L	71-C
CHEMICAL	Composition			Polyelectrolyte
	Ionic Charge	Cationic	Cationic	Cationic
PHYSICAL	Reagent Form	Liquid	Liquid	Powder
	Molecular Weight	Low	Moderate	Very high
	Freezing Point	14° F	14° F	
SOLUTION PREPARATION	Dilution		2–6%	
	Mixing Time	Cold: 5–10 minutes Warm: 4–5 minutes	Warm: 5 minutes Cold: 5+ minutes	30 minutes – 4 hours depending upon size of tank and mixer
	Shelf Life	Reagent: 1 year $>10\%$ Sol'n: several weeks $\leq 10\%$ Sol'n: 1 day	Reagent: 1 year $>10\%$ Sol'n: several weeks $\leq 10\%$ Sol'n: 1 day	Stable in both reagent and sol'n as long as pH is not increased
STORAGE	Reagent			Cool, dry area
	Stock Solution			
	TYPICAL APPLICATIONS	Clarifications filtering and dewatering	Settling, clarifying, thickening and dewatering mineral processing slurries.	Flocculation of solids from water and wastewater; conditioning of sludge; when S.S. 50 ppm, add clay prior to C-7; also can use with inorganics.

(continued)

TABLE A-2. (continued)

	COAGULANT CHARACTERISTICS	REAGENT TRADE NAME		
		Superfloc 315	Alum	Lime (Hydrated)
	CODE	315		
CHEMICAL	Composition	Polyamine	$Al_2(SO_4)_3 \cdot 18\ H_2O$	$Ca\ (OH)_2$ 82-98% $Ca\ (OH)_2$
	Ionic Charge	Highly Cationic		
PHYSICAL	Reagent Form	Liquid	Dry granular powder (grayish white crystallized solid) or alum syrup	Granular powder (white)
	Molecular Weight		600	74.08
	Freezing Point	0°F (-18°C) Can be used after freezing		
SOLUTION PREPARATION	Dilution	0.1 - 5.0 ppm	5 - 50 ppm - application rate	
	Mixing Time		15 - 30 min.	40 min. retention period
	Shelf Life	12-24 months	12 months	12 months
STORAGE	Reagent	In glass, stainless steel, plastic or epoxy lined vessels		
	Stock Solution			package in multiwall paper bags (must be covered)
	TYPICAL APPLICATIONS	Thickening and dewatering mineral concentrates and tailings.	Effective for pH 5.5 to 8.0 removal of suspended and colloridal solids.	

TABLE A-3. PRELIMINARY LABORATORY TEST RESULTS

Abbreviations for Settling Characteristics

ABBREVIATIONS	DESCRIPTION
V.S.S.	Very Slow Settling
S.S.	Slow Settling
F.S.	Fair Settling
G.S.	Good Settling
R.S.	Rapid Settling
C.S.	Clear Supernatant
S.T.S.	Slightly Turbid Supernatant
T.S.	Turbid Supernatant
V.T.S.	Very Turbid Supernatant
S.F.P.	Small Flocced Particles
L.F.P.	Large Flocced Particles
C	Control

Turbidity and Suspended Solids of Control Sample

MODEL SEDIMENT POND	TURBIDITY (JTU)	TSS (mg/l)
PA1	20	32
WV1	44	29
WV2A	7	28
WV3	92	74
WV4	880	1,176
KY1	210	186

(continued)

TABLE A-3. (continued)

Sediment Pond PA-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
3M	1.5	5.2	3.8	81	9	72	R.S.
6A	1.0	5.2	6.0	70	10	69	F.S.
6A	1.5	5.2	5.3	73	12	63	F.S.
6B	0.5	5.2	5.6	72	8	21	F.S.
6B	1.5	5.2	7.4	63	8	75	F.S.
6C	1.5	6.0	4.4	78	9	72	R.S.
6D	1.5	6.0	3.0	85	2	94	F.S.
6E	0.5	5.9	3.6	82	1	97	S.S.
6F	0.5	6.0	4.5	78	10	69	F.S.
15A	1.0	5.7	4.3	79	8	75	F.S.
15A	1.5	5.7	4.3	79	8	75	R.S.

(continued)

TABLE A-3. (continued)

Sediment Pond PA-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
17A	0.5	5.9	4.7	77	15	53	F.S.
17A	1.5	5.7	6.4	68	5	84	R.S.
17B	1.0	5.6	6.1	70	12	63	S.S.
17B	1.5	5.6	4.0	80	19	41	F.S.
17C	0.5	5.5	5.7	72	1	96	S.S.
17C	1.5	5.4	3.8	71	7	78	F.S.
17H	1.0	5.4	3.3	84	1	97	R.S.
22A	1.0	5.0	19	5.0	36	0	V.S.S.
22A	1.5	4.9	20	0	30	6	V.S.S.
30A	1.0	5.1	10	50	2	94	R.S., T.S.
30B	0.5	5.4	2.5	88	5	84	R.S., C.S., L.F.P.

(continued)

TABLE A-3. (continued)

Sediment Pond PA-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
30C	1.5	5.2	2.8	86	1	97	F.S.
30D	1.0	5.1	12	40	11	50	R.S., T.S., L.F.P.
30D	1.5	5.0	9.0	55	19	41	R.S., T.S., L.F.P.
34A	0.5	6.0	4.3	80	6	81	R.S.
44B	1.0	5.1	2.8	86	19	41	R.S.
44B	1.5	5.1	3.6	20	6	81	R.S., L.F.P.
46A	0.5	5.3	6.9	66	5	84	S.S.
46B	0.5	5.1	10	50	15	53	S.S., T.S.
46B	1.0	5.1	12	40	1	97	F.S., T.S.
46C	0.5	5.4	2.0	90	1	97	S.S.
46C	1.0	5.4	3.9	81	<1	100	F.S.

(continued)

TABLE A-3. (continued)

Sediment Pond PA-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
46D	1.5	5.6	6.8	66	1	97	R.S., L.F.P.
46E	0.5	5.4	9.0	55	7	78	F.S.
46F	0.5	5.3	8.0	60	13	59	R.S., T.S.
46F	1.0	5.2	10	50	8	75	R.S., T.S.
61F	0.5	5.7	11	45	13	59	V.S.S.
61F	1.5	5.4	7.3	63	16	50	S.S.
61H	0.5	5.4	7.7	62	9	72	F.S.
61K	1.0	5.2	11	45	23	28	F.S.
61L	0.5	5.2	7.7	61	31	3	F.S.
71C	0.5	5.2	16	20	5	84	S.S., T.S.
Lime	2.2	11	39	>C	74	>C	L.F.P.

(continued)

TABLE A-3. (continued)

Sediment Pond PA-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
Alum	106	3.2	72	>C	86	>C	V.S.S., V.T.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
3M	1.0	7.6	23	48	17	41	R.S., S.T.S.
6A	0.5	6.8	20	55	25	14	S.S., T.S.
6A	1.0	7.1	16	64	32	0	S.S., T.S.
6B	1.5	7.5	3.9	91	10	66	R.S., C.S.
6C	1.0	7.2	16	64	17	41	F.S.
6C	1.5	7.3	13	70	28	3.4	R.S.
6D	1.5	7.6	6.7	85	20	31	F.S.
6E	1.5	7.4	5.2	88	12	59	F.S.
6F	0.5	7.5	12	73	19	34	F.S.
6F	1.5	7.6	7.0	84	21	28	R.S.
15A	1.5	7.4	14	68	22	24	S.S.

(continued)

TABLE A-3. (continued)
Sediment Pond WV-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
17A	1.5	7.6	3.4	92	17	41	F.S., C.S.
17B	1.5	7.3	5.3	88	15	48	F.S.
17C	1.5	7.4	12	73	6	79	R.S., C.S.
17H	1.5	7.6	4.9	89	13	55	S.S.
22A	1.0	7.7	37	16	30	0	V.S.S.
30A	0.5	7.6	21	52	21	28	R.S.
30A	1.5	7.7	24	45	19	34	R.S.
30B	1.0	7.5	29	34	25	14	R.S., T.S.
30C	1.0	7.6	24	45	23	21	R.S., T.S.
30D	1.0	7.5	22	50	19	34	R.S., T.S.
30D	1.5	7.7	26	41	8	72	R.S., T.S.

(continued)

TABLE A-3. (continued)
Sediment Pond WV-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
31A	1.5	7.6	8.0	82	8	72	R.S.
44B	1.0	7.7	17	61	12	59	R.S.
46A	0.5	6.9	5.1	88	8	72	R.S., C.S.
46A	1.0	7.1	5.2	88	1	97	R.S., C.S.
46B	0.5	7.3	8.0	82	13	55	R.S., S.T.
46C	0.5	7.4	11	75	23	21	S.S.
46D	1.0	7.5	15	66	26	10	R.S.
46E	0.5	7.0	6.2	86	16	45	S.S.
46E	1.0	7.1	9.0	80	12	59	R.S.
46F	1.0	7.4	8.2	81	9	69	R.S., T.S.
61F	2.5	7.4	16	64	22	24	R.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
61H	2.5	7.4	7.1	84	19	34	R.S.
61K	2.5	7.5	3.5	92	10	66	R.S.
61L	2.5	7.6	3.5	92	14	52	R.S.
71C	0.5	7.4	30	32	30	0	S.S., T.S.
71C	1.5	7.5	38	14	27	7	S.S., T.S.
Lime	2.4	10.8	37	16	61	>C	L.F.P.
Alum	105	3.3	100	>C	130	>C	V.S.S., V.T.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-2

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
6A	1.0	6.0	5.4	23	10	64	S.S.
6B	1.0	6.1	6.5	7	8	71	S.S.
6C	0.5	6.2	5.1	27	4	86	S.S.
6D	0.5	5.9	4.7	19	6	79	S.S.
6E	1.0	5.8	5.2	27	7	75	F.S.
6F	1.0	5.9	5.2	27	13	54	R.S.
15A	0.5	5.9	4.3	39	13	54	S.S.
17A	0.5	5.8	3.7	47	9	68	S.S.
17B	0.5	5.8	4.9	30	17	40	F.S.
17B	1.5	5.8	6.1	13	14	50	R.S., L.F.P.
17C	0.5	6.0	4.6	34	12	57	S.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-2

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
17H	0.5	5.8	5.5	21	5	82	S.S.
30A	0.5	5.8	5.9	16	26	7	F.S., T.S.
30A	1.0	5.9	4.6	34	30	70	R.S.,L.F.P.
30C	1.0	5.9	2.5	64	24	14	R.S.,L.F.P.
30C	1.5	5.9	2.8	60	20	29	R.S.,L.F.P.
30D	0.5	5.9	3.4	51	12	57	F.S.,L.F.P.
31A	0.5	5.9	5.3	24	12	57	R.S.
44B	1.5	6.0	2.7	64	4	86	R.S., L.F.P.
46A	1.0	6.1	1.9	73	7	75	R.S., L.F.P.
46A	1.5	6.0	2.7	61	3	89	R.S., C.S., L.F.P.
46B	1.0	5.9	2.6	63	8	71	R.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-2

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
46C	0.5	6.0	3.3	46	10	64	F.S.
46D	1.0	6.0	2.8	60	2	93	R.S., L.F.P.
46E	0.5	5.7	4.5	36	10	64	F.S.
46F	0.5	5.9	5.5	21	7	75	R.S., L.F.P.
61F	0.5	6.1	5.7	19	20	29	S.S., T.S.
61F	1.0	6.0	5.2	26	33	0	S.S., T.S.
61H	1.5	6.0	6.0	14	10	64	S.S.
61K	0.5	5.9	5.2	26	14	50	S.S.
71C	0.5	6.0	4.0	43	1	96	S.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-3

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
3M	0.5	7.2	38	59	35	53	F.S.
6A	3.0	6.9	12	87	24	67	S.S., T.S.
6B	3.0	7.0	7.9	91	19	74	F.S.
6C	3.0	6.7	9.6	90	18	76	F.S.
6D	3.0	6.9	10	89	14	81	F.S.
6E	3.0	6.9	5.6	94	20	73	F.S.
6F	3.0	7.1	7.3	92	24	68	F.S.
15A	3.0	7.2	14	85	26	65	F.S.
17A	3.0	6.8	11	88	19	74	R.S.
17B	3.0	7.1	7.8	92	19	74	R.S.
17C	3.0	7.2	22	76	44	41	S.S., T.S.

(continued)

TABLE A-3. (continued)
Sediment Pond WV-3

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
17H	3.0	7.3	7.9	91	27	64	R.S., T.S.
30A	1.5	6.9	32	65	26	65	T.S., G.S.
30B	0.5	7.1	38	59	30	59	T.S., G.S.
30C	3.0	7.2	20	78	9	88	F.S.
30D	1.5	7.1	28	70	20	73	F.S.
31A	3.0	7.0	9.3	90	26	66	F.S.
44B	3.0	7.3	28	70	33	55	S.S., T.S.
46A	3.0	6.7	24	74	27	64	F.S.
46B	1.5	7.0	51	84	64	14	R.S., T.S.
46C	0.5	6.5	20	78	20	73	F.S., S.T.S.
46D	0.5	7.0	36	61	43	42	F.S.

(continued)

TABLE A-3. (continued)
Sediment Pond WV-3

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARACTERISTICS
46E	1.5	6.9	10	89	21	72	F.S.
46F	3.0	7.3	17	82	34	54	F.S.
61F	3.0	6.7	14	85	25	66	S.S., T.S.
61H	3.0	6.9	13	86	20	73	F.S.
61K	3.0	7.1	5.2	94	7	91	F.S.
61L	3.0	7.4	6.4	93	13	82	F.S.
71C	0.5	6.6	76	21	68	8	S.S., T.S.
315	3.0	7.3	17	82	31	58	F.S.

(continued)

TABLE A-3. (continued)
Sediment Pond WV-4

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
3M	1.5	5.9	90	90	66	94	R.S., T.S.
3M	3.0	6.0	80	91	86	93	R.S., T.S.
6A	5.0	6.0	100	89	85	93	F.S., T.S.
6B	5.0	6.0	80	91	68	94	F.S., T.S.
6C	5.0	5.9	61	93	49	96	F.S., T.S.
6D	5.0	6.0	74	92	55	95	S.S., V.T.S.
6E	5.0	6.0	70	92	29	98	F.S., S.T.S
6F	5.0	6.0	58	93	48	96	F.S., T.S.
15A	5.0	6.0	88	90	71	94	F.S., T.S.
17A	5.0	6.3	39	96	37	97	G.S., T.S.
17B	5.0	6.0	11	99	18	98	R.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-4

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARACTERISTICS
17C	5.0	6.3	30	97	47	96	F.S., T.S.
17H	5.0	6.1	22	98	40	97	F.S.
30A	3.0	6.3	180	80	146	88	S.S., T.S.
30B	5.0	6.1	120	86	120	90	S.S., V.T.S., L.F.P.
30C	3.0	6.2	160	82	150	87	S.S., V.T.S., L.F.P.
30D	5.0	6.1	180	80	134	89	S.S., V.T.S., L.F.P.
31A	5.0	6.1	25	97	21	98	R.S., S.T.S.
44B	5.0	6.3	32	96	36	97	R.S., T.S.
46A	5.0	6.0	98	89	62	95	R.S., V.T.S.
46B	5.0	6.2	180	80	220	81	S.S., V.T.S.
46C	1.5	6.3	210	76	204	83	S.S., V.T.S.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-4

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
46C	5.0	6.2	140	84	218	81	S.S., V.T.S.
46D	5.0	6.3	90	90	148	87	S.S., L.F.P.
46E	1.5	6.2	32	96	43	96	F.S., S.T.S.
46E	5.0	6.2	17	98	48	96	R.S.
46F	3.0	6.3	24	97	35	97	S.S., T.S.
61F	5.0	6.0	160	82	158	87	S.S., T.S.
61A	5.0	6.0	210	76	170	86	V.S.S., V.T.S.
61K	5.0	6.0	53	94	46	96	R.S., T.S.
61L	5.0	6.0	74	92	88	93	R.S., T.S.
71C	5.0	6.3	400	54	232	80	S.S, V.T.S.
Lime	1.2	10.7	32	96	57	94	L.F.P.

(continued)

TABLE A-3. (continued)

Sediment Pond WV-4

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
Alum	110.6	3.1	120	86	180	85	V.S.S., V.T.S.

(continued)

TABLE A-3. (continued)

Sediment Pond KY-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
3M	1.5	7.0	30	86	18	90	R.S., T.S., L.F.P.
6A	5.0	6.5	52	75	52	82	S.S., T.S.
6B	5.0	6.0	52	75	34	82	S.S., T.S.
6C	5.0	6.6	46	78	40	78	S.S., T.S.
6D	5.0	6.7	46	78	50	73	S.S., T.S.
6E	5.0	6.8	43	80	35	81	S.S., T.S.
6F	5.0	6.8	69	67	60	68	S.S., T.S.
15A	5.0	6.8	70	67	70	62	S.S., T.S.
17A	5.0	6.8	58	72	67	64	S.S., T.S.
17B	5.0	6.8	40	81	92	51	S.S., T.S.
17C	5.0	6.8	43	80	43	77	S.S., T.S.

(continued)

TABLE A-3. (continued)
Sediment Pond KY-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
17H	5.0	6.8	52	75	74	60	S.S., T.S.
30A	1.5	6.9	38	82	34	82	R.S., T.S., L.F.P.
30B	1.5	6.9	28	87	48	74	R.S., T.S., L.F.P.
30C	1.5	7.0	70	67	58	69	R.S., T.S.
30D	5.0	7.0	50	81	70	62	R.S., T.S., L.F.P.
31A	5.0	6.8	44	79	46	75	R.S., T.S.
44B	5.0	6.9	24	89	66	65	R.S., T.S., G.S., L.F.P.
46A	1.5	6.9	42	80	34	82	S.S., T.S.
46B	5.0	6.8	46	78	64	66	R.S., T.S., L.F.P.
46C	1.5	6.6	87	59	94	50	R.S., T.S., L.F.P.
46D	3.0	6.9	33	84	60	73	R.S., T.S., L.F.P.

(continued)

TABLE A-3. (continued)
Sediment Pond KY-1

COAGULANT	DOSAGE (ppm)	pH	TURBIDITY (JTU)	PERCENT REMOVAL	SUSPENDED SOLIDS (mg/l)	PERCENT REMOVAL	SETTLING CHARAC-TERISTICS
46E	5.0	6.9	14	93	19	90	R.S., T.S., L.F.P.
46F	3.0	6.8	16	92	15	92	R.S., T.S., L.F.P.
61F	5.0	6.0	69	67	64	66	S.S., T.S.
61H	5.0	6.1	85	60	82	56	S.S., T.S.
61K	5.0	6.6	92	56	62	67	S.S., T.S.
61L	5.0	6.6	86	59	81	56	S.S., T.S.
71C	5.0	6.6	14	93	16	91	G.S., T.S., S.F.P.
315	5.0	6.9	44	79	49	74	S.S., T.S.
Lime	1.7	10.9	34	84	74	60	R.S.
Alum	106.5	3.1	43	80	66	65	V.S.S., V.T.S.

TABLE A-4. BENCH SCALE TREATABILITY STUDY RESULTS

Magnifloc 587C

	TEST WATER											
DOSAGE (ppm)	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
RAW	880	437	440	2,306	64	148	200	4,510	440	2,454	680	606
CONTROL	20	32	44	29	7.0	28	92	74	880	1,176	210	186
0.5	3.6	1	7.1	12	5.1	11	28	20	*			
1.0	3.5	12	6.4	17	5.2	7						
1.5	3.4	14	5.2	12	5.0	11	9.0	20	200	140	82	70
2.0			8.9	6								
3.0			6.5	5			5.6	20	100	90	54	43
4.0			6.4	6								
5.0							9.2	14	70	29	43	35

*Blank spaces indicate no test at this dosage

(continued)

TABLE A-4. (continued)

Magnifloc 587C

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
6.0									9.6	12	12	12
7.0							26	33				
8.0									8.8	12	12	19
10.0							33	41	9.2	14	14	19

(continued)

TABLE A-4. (continued)
M-502

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
RAW	880	437	440	2,306	64	148	200	4,510	440	2,454	680	606
CONTROL	20	32	44	29	7.0	28	92	74	880	1,176	210	186
0.5	4.4	5	14	21	5.5	5	64	72				
1.0	3.3	1	8.4	13	6.1	18						
1.5	3.4	1	4.9	13	6.7	21	14	34	90	86	100	102
2.0			5.2	4								
3.0			6.3	7			7.9	27	31	52	80	92
4.0			6.5	15								
5.0							27	44	22	40	52	74

(continued)

TABLE A-4. (continued)

M-502

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
6.0									16	11	20	22
7.0							38	43				
8.0									13	23	20	21
10.0							43	65	13	23	20	21

(continued)

TABLE A-4. (continued)
Amerfloc 485

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
RAW	880	437	440	2,306	64	148	200	4,510	440	2,454	680	606
CONTROL	20	32	44	29	7.0	28	92	74	880	1,176	210	186
0.5	4.3	6	18	31	5.3	12	28	39				
1.0	3.9	12	12	18	6.2	11						
1.5	5.7	19	8.0	8	6.2	11	9.3	26	90	79	81	86
2.0			8.4	9								
3.0			8.6	10			9.0	25	37	27	51	56
4.0			7.2	13								
5.0							38	46	25	21	44	46

(continued)

TABLE A-4. (continued)
Amerfloc 485

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
6.0									6.6	10	14	21
7.0							54	62				
8.0									6.2	11	14	21
10.0							56	66	7.2	11	14	18

(continued)

TABLE A-4. (continued)
Polyfloc C

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
RAW	880	437	440	2,306	64	148	200	4,510	440	2,454	680	606
CONTROL	20	32	44	29	7.0	28	92	74	880	1,176	210	186
0.5	4.2	16	18	19	2.3	22	98	116				
1.0	2.8	19	17	12	2.4	22						
1.5	3.6	6	20	11	2.7	4	54	66	100	114	34	82
2.0	6.8	15	20	30	2.2	7						
3.0	8.5	21	20	52			28	33	53	45	30	65
4.0			24	50								
5.0							9.3	10	32	36	24	66

(continued)

TABLE A-4. (continued)

Polyfloc C

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
6.0									30	32	28	14
7.0							10	24				
8.0							10	30	32	25	32	34
10.0									36	50	33	44

(continued)

TABLE A-4. (continued)

Hercofloc 812

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
RAW	880	437	440	2,306	64	148	200	4,510	440	2,454	680	606
CONTROL	20	32	44	29	7.0	28	92	74	880	1,176	210	186
0.5	6.9	5	5.1	8	2.1	9	74	62				
1.0	12	9	5.2	1	1.9	7						
1.5	9	8	6.5	6	2.7	3	29	26	360	240	42	34
3.0							24	27	140	108	42	43
5.0							7.3	8	98	62	40	45
6.0									28	19		
7.0							6.7	4				

(continued)

TABLE A-4. (continued)

Hercofloc 812

DOSAGE (ppm)	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TEST WATER											
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
8.0									30	21		
10.0							6.6	22	30	30		

(continued)

TABLE A-4. (continued)

Hercofloc 831

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
RAW	880	437	440	2,306	64	148	200	4,510	440	2,454	680	606
CONTROL	20	32	44	29	7.0	28	92	74	880	1,176	210	186
0.5	15	15	15	31	2.8	11	36	43			46	42
1.0	8.7	6	15	26	2.8	2	24	14	34	20		
1.5	6.8	1	17	32	3.3	3	57	94	140	182	43	50
2.0			31	30								
2.5	10	34					34	20				
3.0	22	44	32	30			53	92	90	152	33	60
4.0			31	30								

(continued)

TABLE A-4. (continued)
Hercofloc 831

DOSAGE (ppm)	TEST					WATER						
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
5.0							38	38	90	148	40	56
6.0									90	78		
7.0											40	44
8.0									90	64		
10.0									88	64	30	44

(continued)

TABLE A-4. (continued)

Superfloc 315

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
RAW	880	437	440	2,306	64	148	200	4,510	440	2,454	680	606
CONTROL	20	32	44	29	7.0	28	92	74	880	1,176	210	186
0.5	6.8	15	18	37	2.8	9	74	80	90	95		
1.0	6.9	17	10	35	2.5	9			52	55		
1.5	6.8	17	8.0	29	2.6	10	26	35	26	44	75	64
2.0	6.8	16	6.4	13	2.7	9						
3.0	6.4	21	6.6	8	2.8	14	17	31	19	1	54	54
4.0			6.2	6								
5.0			6.4	9	2.6	16	7.0	19	12	3	44	49

(continued)

TABLE A-4. (continued)

Superfloc 315

DOSAGE (ppm)	TEST WATER											
	PA-1		WV-1		WV-2A		WV-3		WV-4		KY-1	
	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)	TURB (JTU)	TSS (mg/l)
6.0									12	13	18	19
7.0							7.2	19				
8.0									14	20	19	26
10.0							5.0	12	18	23	18	27

TABLE A-5. SUMMARY OF BENCH-SCALE TREATABILITY STUDY

Optimum Dosage (21° C)*

TEST WATER	▨	MAGNIFLOC 587C	M-502	AMERFLOC 485	HERCOFLOC 812	HERCOFLOC 831	POLYFLOC C	SUPERFLOC 315
PA-1	TURB	1.5	1.0	1.0	0.5	1.5	1.0	3.0
	TSS	0.5	1.0	0.5	0.5	1.5	1.5	0.5
WV-1	TURB	1.5	1.5	4.0	0.5	0.5	1.0	4.0
	TSS	3.0	3.0	2.0	1.0	1.0	1.5	4.0
WV-2A	TURB	1.5	0.5	0.5	1.0	0.5	0.5	1.0
	TSS	1.0	0.5	1.0	1.5	1.0	2.0	0.5
WV-3	TURB	3.0	3.0	3.0	10.0	1.0	5.0	10.0
	TSS	5.0	3.0	3.0	7.0	1.0	5.0	10.0
WV-4	TURB	8.0	8.0	5.0	6.0	1.0	6.0	5.0
	TSS	6.0	6.0	6.0	6.0	8.0	8.0	3.0
KY-1	TURB	6.0	6.0	6.0	5.0	10.0	5.0	6.0
	TSS	6.0	8.0	6.0	1.5	0.5	6.0	6.0

(continued)

* Optimum dosages in mg/l.

TABLE A-5. (continued)

At Optimum Dosage (21° C)*

TEST WATER	▨	MAGNIFLOC 587C	M-502	AMERFLOC 485	HERCOFLOC 812	HERCOFLOC 831	POLYFLOC C	SUPERFLOC 315
PA-1	TURB	83.0	83.5	80.5	65.5	66.0	86.0	68.0
	TSS	96.8	96.8	81.3	84.4	97.8	97.8	53.1
WV-1	TURB	88.2	88.2	83.6	88.4	66.0	61.4	86.0
	TSS	82.8	76.0	69.0	96.5	10.3	62.1	79.3
WV-2A	TURB	28.6	21.4	24.3	72.9	60.0	68.6	64.3
	TSS	75.0	82.1	60.7	86.0	92.9	90.0	67.9
WV-3	TURB	93.9	91.4	90.2	92.7	74.0	89.9	45.7
	TSS	81.1	63.5	66.2	94.6	81.1	86.5	83.8
WV-4	TURB	99.0	98.5	99.3	96.8	96.1	96.6	98.6
	TSS	99.0	93.5	99.1	98.4	95.0	97.9	99.9
KY-1	TURB ●	94.3	90.5	93.3	80.0	85.7	88.6	91.4
	TSS	93.5	88.7	88.7	81.7	77.4	92.5	89.8

* Efficiency of removal in percent.

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